CHAPTER 9. LIFE-CYCLE COST ANALYSIS

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CHAPTER 9. LIFE-CYCLE COST ANALYSIS

9.1 INTRODUCTION

9.1.1 Overview

The life-cycle cost (LCC) analysis examines the economic impacts on individual consumers from possible revisions to U.S. residential water heater energy-efficiency standards. LCC represents the consumer's cost of purchasing and installing a water heater and operating it for its lifetime. We also calculate payback periods for consumers for each of the water heater designs considered.

The LCC that we calculate expresses, in 1998$, the costs of owning and operating a water heater for its lifetime starting in the year 2004. We analyze various water heater models: a "2003 baseline" design, which is what we anticipate will be the standard design in 2003 prior to any new efficiency standards, as well as various "design options"—models with additions to the baseline, which represent efficiency improvements that meet possible energy-efficiency standards. These design options, which are chosen in the Engineering Analysis (see Chapter 8), are the same in each of the five modules that make up the LCC and are described in Tables 9.1.1 through 9.1.4 below. They include an "existing baseline," which represents water heaters in use in 1998. We consider water heaters fueled by electricity, gas (both natural gas and LPG),[a] and oil. The "2003 baseline" also accounts for changes in water heater insulation that will result from the elimination of the use of HCFC-141b, a blowing agent which damages earth's ozone layer and is scheduled by the U.S. EPA to be phased out by January 1, 2003. We analyze designs utilizing HFC-245fa insulation, one of the current leading candidates to replace HCFC-141b. For natural gas and LPG water heaters, we also include a design change to resist ignition of flammable vapors (see Chapter 3.4.2) in the "2003 baseline".

The LCC spreadsheet contains five modules. For the variables in each of the five modules, we use specific strategies to characterize uncertainty and variability, which are explained in the sections below that describe each module in detail. The analysis uses the Monte Carlo statistical method to calculate life-cycle cost. Monte Carlo analyses capture the effects of variability and uncertainty in input variables on the output variables. In this analysis, we sample 10,000 times from a distribution on each input value using Crystal Ball. Crystal Ball (available from Decisioneering, Inc.) is an add-in program to Microsoft Excel, which performs the Monte Carlo calculations. The final LCC results—percent of population benefitting (winners) from energy-efficiency improvements and the mean LCC changes—are derived from these Crystal Ball runs. In general, our analysis uses distributions, instead of fixed values, to account for variability and uncertainty in the variables. For detailed information about our uncertainty and variability analyses, see Appendix E-1.

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[a] Water heaters fueled by natural gas and LPG are considered as one product class from the point of view of physical and efficiency characteristics. They are treated separately with respect to manufacturing cost, markup, retail price, and fuel price in the Life-Cycle Cost and subsequent analyses.

The first of the five LCC modules, the Hot Water Draw Module, is used to calculate the amount of hot water used by each household. The households are in a large sample that is taken from U.S. DOE/EIA's 1997 *Residential Energy Consumption Survey* (RECS) database for the electric, natural gas, and LPG analyses[1] and from the 1993 RECS[2] for oil-fired water heaters.[a] RECS' characterization of water heater sizes as small, medium, and large for each household is translated into the most common sizes on the market for water heaters of each fuel type. We refer to these as "standard sizes." In some cases, where we rely on data from the Engineering Analysis (Chapter 8), we refer to the three "typical" water heater sizes used in that analysis, i.e., 50-gal. electric, 40-gal. natural gas and LPG, and 32-gal. oil-fired. We analyze a random selection of RECS households, using a RECS weighting factor that accounts for how common each household configuration is in the general population. A total of 3531 households were selected from the 1997 RECS database for the electric, natural gas, and LPG LCC analysis and 176 households from the 1993 RECS database were used for the oil-fired water heater analysis. For each water heater type, we sample from this subset of households 10,000 times. Extensive Monte Carlo analyses (using Crystal Ball) address uncertainty and variability in the household variables.

The second module in the LCC, the Energy Analysis Module, is used to calculate how much energy of what type (electricity, natural gas, LPG, or oil) is used in each household analyzed in the Hot Water Draw Module. We consider the 2003 baseline and design options for each size water heater of each fuel type. The analysis accounts for the use of electricity required by some design options for natural gas, LPG, and oil-fired water heaters.

The third LCC module, Operating Costs, is used to determine the annual cost of operating each type of electric, natural gas, LPG, or oil water heater—i.e., the 2003 baseline and all design options—for the same households analyzed in the previous two modules. We include average annual maintenance costs for oil-fired water heaters (electric, gas, and LPG water heaters do not require annual maintenance). We calculate annual water heater operating costs for its lifetime starting in 1998 by taking the annual energy consumption calculated by the Energy Analysis Module and applying the average fuel cost from RECS for each household analyzed. We translate RECS cost data to 1998$ using historical inflation and energy price change rates. We project future costs over the water heater lifetimes using DOE's Energy Information Agency (EIA) and Gas Research Institute (GRI) forecasts. We calculate the value of savings from the energy-efficient design options using marginal prices, which are weighted according to seasonal water heater energy consumption. A discussion of marginal prices is presented in Section 9.4.

The fourth module in the LCC analysis, the Equipment Cost Module, is used to calculate a consumer's cost to purchase and install the 2003 baseline and design option water heaters of each size and fuel type. This calculation uses manufacturers' costs from the Engineering Analysis, with adjustments to account for the water heater sizes chosen for the LCC and for typical retail markups for water heaters of each fuel type. We determined these markups from data collected during

[a] We did not update the oil-fired analysis when the 1997 data became available because only a small number of households use oil-fired water heaters.

interviews with retailers, wholesalers, plumbers, contractors, and utilities (see Chapter 7, Markups). We also gathered information on installation prices. We account for sales tax and other costs consumers pay: delivery fees, permit fees, or fees for removal of old water heaters. These taxes and fees are added randomly to the purchase and installation costs for some water heaters. We also incorporate additional installation costs (e.g., for new electrical connections or venting upgrades) for some efficiency options.

The final step in the analysis, the LCC module, is used to determine the life-cycle cost and payback for each water heater design option for the sample of RECS houses we studied. We calculate LCC by taking the annual operating costs from a previous module for the lifetime of a water heater and discounting these costs to the year 1998 using a distribution of discount rates from an existing appliance standards analysis for clothes washers.[3] The equipment lifetimes considered are the same for all design options but differ by fuel type; these values were taken from a published survey.[4]

The five modules that make up the LCC analysis are explained in detail in the following sections.

Tables 9.1.1 through 9.1.4 list the design options analyzed in this Technical Support Document. In general and throughout this document, the "Short Name" is used to identify the individual design options. These tables provide the full list of the individual combinations of design features that make up the design options (these tables are also found at end of the Engineering Analysis in the preceding chapter)

Table 9.1.1 Definition of Design Options for Electric Water Heaters

Short Name	Full Description
2003 Baseline	Baseline (245fa)
Heat Traps	2003 Baseline + Heat Traps
Tank Bottom Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation
2" Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation + 2" Insulation
2.5" Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation + 2.5" Insulation
Plastic Tank	2003 Baseline + Heat Traps + 2.5" Insulation + Plastic Tank
3" Insulation	2003 Baseline + Heat Traps + 3" Insulation + Plastic Tank

Table 9.1.2 Definition of Design Options for Natural Gas Water Heaters

Short Name	Full Description
2003 Baseline	Baseline (245fa)
Heat Traps	2003 Baseline + Heat Traps
78% RE	2003 Baseline + Heat Traps + 78% RE
78% RE, 2" Insul	2003 Baseline + Heat Traps + 78% RE + 2" Insulation
78% RE, 2.5" Insul	2003 Baseline + Heat Traps + 78% RE + 2.5" Insulation
80% RE, 2" Insul	2003 Baseline + Heat Traps + 80% RE + 2" Insulation
80% RE, 2.5" Insul	2003 Baseline + Heat Traps + 80% RE + 2.5" Insulation
80% RE, 3" Insul	2003 Baseline + Heat Traps + 80% RE + 3" Insulation
Side Arm	2003 Baseline + Heat Traps + 80% RE + 3" Insulation + Side Arm + Electronic Ignition + Plastic Tank

RE= Recovery Efficiency

Table 9.1.3 Definition of Design Options for LPG Water Heaters

Short Name	Full Description
2003 Baseline	Baseline (245fa)
Heat Traps	2003 Baseline + Heat Traps
78% RE	2003 Baseline + Heat Traps + 78% RE
78% RE, 2" Insul	2003 Baseline + Heat Traps + 78% RE + 2" Insulation
78% RE, 2.5" Insul	2003 Baseline + Heat Traps + 78% RE + 2.5" Insulation
80% RE, 2" Insul	2003 Baseline + Heat Traps + 80% RE + 2" Insulation
80% RE, 2.5" Insul	2003 Baseline + Heat Traps + 80% RE + 2.5" Insulation
80% RE, 3" Insul	2003 Baseline + Heat Traps + 80% RE + 3" Insulation
Side Arm	2003 Baseline + Heat Traps + 80% RE + 3" Insulation + Side Arm + Electronic Ignition + Plastic Tank

RE= Recovery Efficiency

Table 9.1.4 Definition of Design Options for Oil-Fired Water Heaters

Short Name	Full Description
2003 Baseline	Baseline (245fa)
Heat Traps	2003 Baseline + Heat Traps
2" Insulation	2003 Baseline + Heat Traps + 2" Insulation
2.5" Insulation	2003 Baseline + Heat Traps + 2.5" Insulation
3" Insulation	2003 Baseline + Heat Traps + 3" Insulation
78% RE	2003 Baseline + Heat Traps + 3" Insulation + 78% RE
Interrupted Ignition	2003 Baseline + Heat Traps + 3" Insulation + 78% RE + Interrupted Ignition
Increased HX Area	2003 Baseline + Heat Traps + 3" Insulation + Interrupted Ignition + Increased Heat Exchanger Area (82% RE)

9.1.2 General Description of Sources of Data

9.1.2.1 Residential Energy Consumption Survey

The analysis uses as its underlying data source the *Residential Energy Consumption Survey* (RECS), now formally called the *Household Energy Consumption and Expenditures.* RECS contains a more complete set of data for water heater analysis than any other survey reviewed for this study. RECS data include household characteristics taken from an interview questionnaire and annual fuel consumption and expenditures (excluding transportation fuel) derived from the records of fuel suppliers. Also included are weather data and a weighting variable to account for variations in household composition. The 1997 RECS survey consists of a total of 5,900 sample households from the 50 states and the District of Columbia. See Table 9.1.5 for the household characteristics of the RECS sample used in the analysis. Table 9.1.6 shows the number of records and their weighted values that were not used in this analysis. Of the total 5,900 housing records (a weighted population of 101,481,171), a total of 2,283 housing records (representing a 37,696,171 population) were not used in the analysis.

Table 9.1.5 1997 RECS Household Characteristics[a]

	Electricity	Natural Gas	LPG	Oil
Number of Households (records)	1577	1802	152	176
Number of Households (millions, weighted)	27.2	33.2	2.3	1.8
Household Size (average number of people)	2.45	2.82	2.58	2.87
Clothes Washer (% saturation)	83.2%	89.8%	88.7%	96.6%
Dishwasher (% saturation)	54.1%	55.3%	39.6%	56.8%
Average Thermostat Setpoint (EF)	133.2	134.5	135.4	137.5
Average Inlet Water (EF)	59.6	57.2	55.6	51.8
Average Hot Water Use (gals per day)	45.3	49.9	45.7	47.3

Table 9.1.6 Profile of RECS Households Not Used in Consumer Sub-Group Analysis

Category	# of RECS Housing Records	% Household Population (weighted)
Other Fuel Types	53	0.8
Shared WH Unit	640	10.3
No Water Heater Size Indicated	901	14.1
No LPG Quantity Indicated	270	3.7
No Fuel Oil Quantity Indicated	2	0.0
Insufficient Billing Data for Electric Water Heaters	1524	24.9
Insufficient Billing Data for Gas-Fired Water Heaters	766	13.1
Unused Sample Size	2,283	37.1

9.1.2.2 National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce, operates the National Climatic Data Center, which is the world's largest active archive of weather data. This analysis uses NOAA's 30-year (1961-1990) average air temperatures.[5]

[a] Data for oil-fired water heaters is from the 1993 RECS database.

9.1.2.3 Gas Appliance Manufacturers Association

The Gas Appliance Manufacturers Association (GAMA) is a national trade organization which represents water heater manufacturers in the U.S. GAMA collects and disseminates data on water heating equipment. This analysis uses GAMA's shipments data, consumers' directory, and manufacturer costs for most design options.

9.1.2.4 Manufacturer Product Literature

Most manufacturers of water heaters provide dealers (and consumers) with literature describing their models, including efficiency ratings. A large collection of manufacturer product literature was assembled and consulted for this analysis.

9.1.3 Spreadsheet Model

A spreadsheet model with five major modules forms the basis of the LCC calculations. The major modules are LCC and Payback, Equipment Cost, Operating Cost , Energy Analysis, and Hot Water Draw. Seven supporting sheets provide data for the calculations (Energy Price Data, Discount Rate, Cost Data, Energy Price Data, Markup, and RECS Sample). The last two worksheets contain RECS sub-population records: senior-only and low-income families. Each module has its own inputs and outputs, with some modules using as inputs the outputs of other modules. To provide a general overview, a flowchart showing the major sections of the spreadsheet and the data flow between the modules is presented below in Figure 9.1.1.

An introductory worksheet presents a brief description of the spreadsheet model and implementation procedures. It allows the user to select 1) a starting year for the LCC calculation, 2) a starting year for the payback calculation, 3) scenarios for future energy prices, and 4) population groups that allow sub-group simulations. There is a separate spreadsheet available for each type of water heater being considered: electric, natural gas, LPG, and oil-fired. The LCC spreadsheets are available on the DOE web site.[6]

For this analysis, we ran the LCC spreadsheet using a base case scenario, the 2000 Reference Case from DOE/EIA's *Annual Energy Outlook 2000*[7] (see Section 9.4.4 below for details)[a]. We also ran the model using three alternative future energy price scenarios. The results are presented in Appendix E-4.

The main outputs of each module are summarized as tables and charts in the individual sections. The summaries for each module give outputs by design option, except for the Hot Water

[a] For the oil-fired analysis, the reference case from the *Annual Energy Outlook 1998* was used. The oil-fired analysis was not updated because only a small number of households use oil-fired water heaters.

Draw module. The Draw module calculates hot water use for each household sample. The amount of hot water use is not affected by water heater efficiency, so it is not calculated separately for each design option.

The summary tables list the average value for each output and the percent of households that would benefit by using that design option. For example, in the LCC and Payback module, the values reported in the tables are LCC and Payback. In other modules, other outputs are reported as appropriate.

The impact of individual design options are shown in combined histogram and cumulative frequency charts. These charts show the output by percent of the population. The bars of the histograms show the relative frequency of different results out of 10,000 samples from each subset of RECS households (1577 with electric water heaters, 1802 with natural gas, 152 with LPG, and 176 with oil-fired). RECS household weightings were used to select the samples. The lines show cumulative percentages of the results for each value.

The final type of chart is a tornado chart, which shows the correlations between the inputs of each module and the output in question. The importance of each input is measured as the rank-order correlation between each input and the output of interest. The higher the absolute value of the correlation, the more influence the input has on the output. A negative correlation indicates a decrease in output in response to an increase in the input.

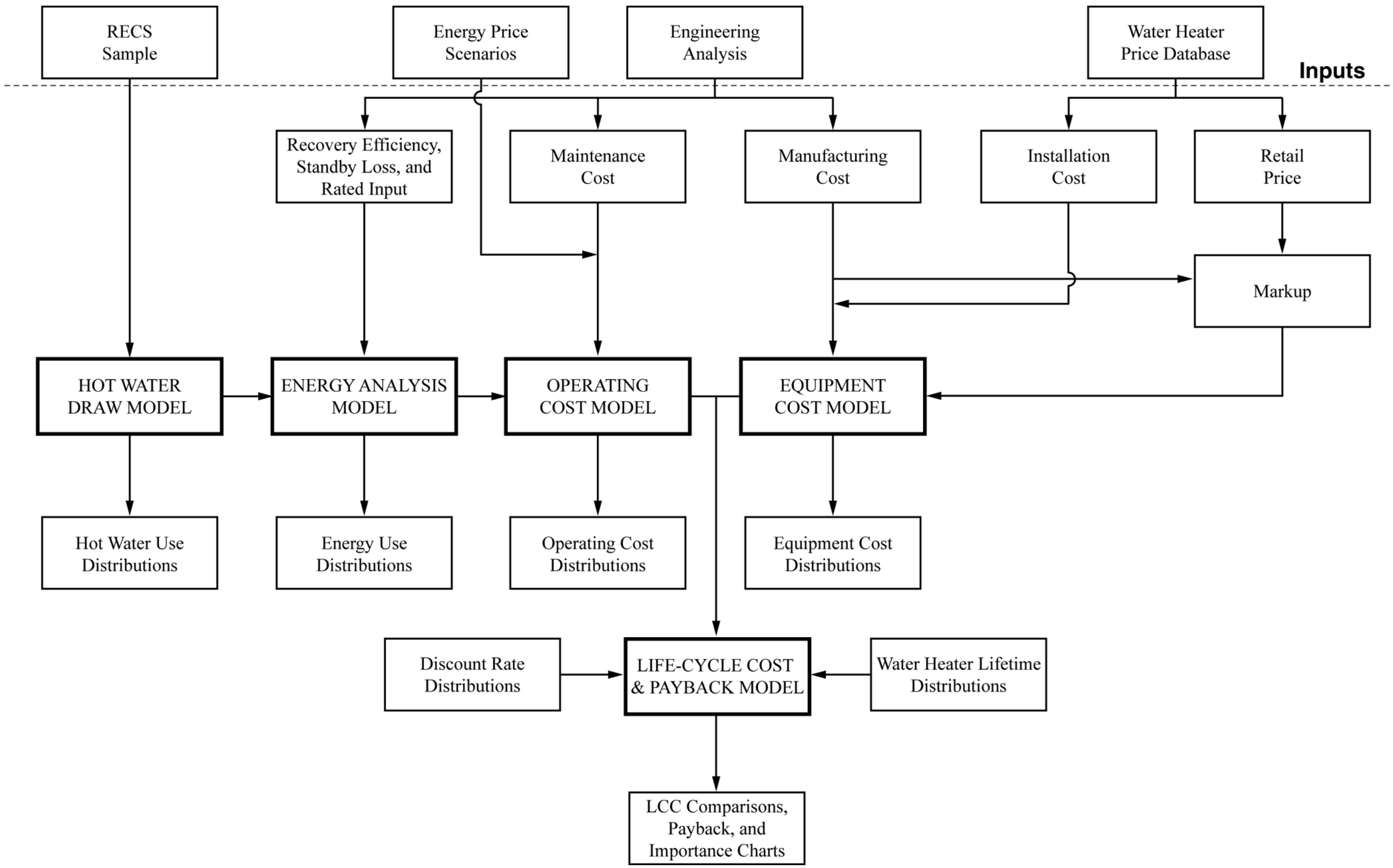

Figure 9.1.1 Flowchart of LCC Spreadsheet

9.2 HOT WATER DRAW MODULE

9.2.1 Introduction to Hot Water Use

Hot water use varies widely among households because it depends on household and water heater characteristics, including: the number and age of the people who live in a home and the way they consume hot water, the presence of hot water-using appliances, the tank size and thermostat setpoint of the water heater, and the climate in which the home is situated. By accounting for these five types of characteristics, the Hot Water Module estimates average daily volume of hot water used by households.[8]

There is a degree of uncertainty in this estimation of hot water use because of errors associated with the estimated coefficients in the equation. The uncertainties in the coefficients are defined using normal distributions with the parameters provided in a regression analysis described in a study prepared for the Electric Power Research Institute (EPRI).[9] Crystal Ball was used to characterize hot water use based on uncertainty and variability in inputs to the equation shown below.

9.2.2 Equation for Hot Water Use

The Hot Water Draw Model was developed by LBNL as an improvement on a previously existing EPRI model.[8] The equation is expressed as follows:

$$
\begin{aligned}
vol = \{ & sea\_coef + (per\_coef * per) + (age1\_coef * age1) + (age2\_coef * age2) + \\
& [age34\_coef * (age3 + age4)] + [T_{tank}\_coef * (T_{tank} + T_{tank}\_err)] + \\
& (Tanksz\_coef * Tanksz) + (T_{in}\_coef * T_{in}) + (T_{air}\_coef * T_{air}) + \\
& (home\_coef * athome) - [(0.692 * per + 1.335 * \%per) * no\_dw] - \\
& [(1.1688 * per + 4.7737 * \%per) * no\_cw] \} * (senior\_mf * senior\_mf\_coef \\
& * no\_pay * no\_pay\_coef)
\end{aligned}
$$

where:

vol = hot water consumption, gal/day

per = total number of persons in household

age1 = number of preschool children, age 0-5 yrs

age2 = number of school age children, age 6-13 yrs

age3 = number of adults, age 14-64 yrs

age4 = number of adults, age 65 yrs and over

T_{tank} = water heater thermostat setting, °F

*Tank*sz = water heater nominal tank size, gal

T_{in} = water heater inlet water temperature, °F

T_{air} = outside air temperature, °F

athome = presence of adults at home during day

no_dw = absence of a dishwasher

no_cw = absence of a clothes washer

senior_mf = senior-only household in a multi-family building

no_pay = household does not pay for hot water

.

T_{tank}*_err* = estimation error for the thermostat setpoint (normal distribution)

sea_coef = coefficient for seasonal effects (normal distribution)

per_coef = coefficient for total number of persons in household (normal distribution)

age1_coef = coefficient for "age1" (normal distribution)

age2_coef = coefficient for "age2" (normal distribution)

age34_coef = coefficient for "age3" + "age4" (normal distribution)

home_coef = coefficient for "athome" (normal distribution)

Tanksz_coef = coefficient for water heater tank size (normal distribution)

T_{tank}*_coef* = coefficient for water heater setpoint (normal distribution)

T_{inlet}*_coef* = coefficient for water heater inlet temperature (normal distribution)

T_{air}*_coef* = coefficient for average outside temperature (normal distribution)

senior_mf_coef = coefficient for senior-only household in a multi-family building (normal distribution)

no_pay_coef = coefficient for household does not pay for hot water (normal distribution)

9.2.3 General Description of Key Variables

Number of Persons in Household (per). The total number of household members.

Number of Preschool Children 0-5 (age1). The equation calls for the number of infants and young children ages 0-5. However, unlike previous versions of RECS, the 1997 RECS bins ages of household members. The closest age bin was infants 0-1, so that is what was used. This will underestimate hot water usage due to this age category.

Number of School-Age Children 6-13 (age2). The equation calls for the number of children, ages 6 through 13. The closest age bin available in RECS was used, children 1-12. Hot water usage due to this category will therefore be somewhat overestimated.

Number of Adults 14-64 (age3). The equation calls for the number of adults, ages 14 to 64. The closest RECS bin was used, ages 13 to 64. Hot water usage in this age category will be very slightly overestimated.

Number of Adults 65+ (age4). The equation calls for number of adults, ages 65 or older. There is a RECS age category that corresponds to this.

Thermostat Setpoint (T_{tank}). The thermostat setting of the water heater.

Water Heater Tank Size (Tanksz). The nominal size of the water heater tank.

Outside Air Temperature (T_{air}). The average annual outside air temperature.

Inlet Water Temperature (T_{in}). The temperature of the water entering the water heater.

Household Member (athome). The presence of an adult household member at home during the day.

Dishwasher (no_dw). Absence of a dishwasher in the household.

Clothes Washer (no_cw). Absence of a clothes washer in the household.

Senior Only (senior_mf). A senior-only (age 65 or more) household in a multi-family building.

No-Pay Household (no_pay). A household that does not pay to heat water.

9.2.4 General Description of Data Sources

The 1997 *Residential Energy Consumption Survey* (RECS)[1] is the primary source of data for the LCC analysis[a]. Most, but not all, RECS household records are used in the analysis. We assume that the household records used, with their weighted averages, are representative of housing nationwide. Our analysis includes only RECS households that have five defining features:

1. Running hot water
2. An individual water heater
3. An indication of water heater size (small, medium, or large)
4. One of four fuels: electricity, gas, LPG, or oil
5. Sufficient data to calculate marginal energy price

We use EIA weightings for each RECS household; these values indicate how commonly each household configuration occurs in the general population.

RECS sometimes reports ranges rather than precise numbers for variables and lacks some crucial information needed for our analysis. To correct for these missing or insufficient data, we applied two methods: (1) when ranges were given, we made best-point estimates within the range; and (2) when RECS data did not cover particular areas of interest to us, we used other studies to develop the necessary information.

RECS provides data on the number, age, and employment status of household occupants, the presence of a clothes washer or dishwasher, and the form of payment to fuel utilities.

The derivations of temperature variables for water heater thermostat setpoint, inlet water temperature, and temperature of air surrounding the water heater are discussed in Section 9.3.4.2.

RECS reports three ranges of water heater tank size — small, medium, and large. For our hot water draw analysis, however, specific sizes are needed. We used the three RECS ranges plus the reported number of bathrooms in the house, as listed in Table 9.2.1, to assign an exact water heater size to each RECS house.

Table 9.2.1 shows, by fuel type, the RECS water heater volumes and the corresponding selections for this analysis.

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[a] The 1993 RECS was used for oil-fired water heaters. The oil-fired analysis was not updated because only a small number of households use oil-fired water heaters.

Table 9.2.1 Water Heater Sizes Selected for LCC Analysis

<table>
<tr><th></th><th>RECS size</th><th>RECS no. of bathrooms</th><th>"Standard" Sizes Selected for LCC Analysis (gal) (liters)</th></tr>
<tr><td rowspan="6">Electric</td><td>Small</td><td>all</td><td>30 (110)</td></tr>
<tr><td rowspan="2">Medium</td><td>0 or 1</td><td>40 (150)</td></tr>
<tr><td>2 or more</td><td>50 (190)</td></tr>
<tr><td rowspan="3">Large</td><td>0 or 1</td><td>50 (190)</td></tr>
<tr><td>2</td><td>65 (250)</td></tr>
<tr><td>3 or more</td><td>80 (300)</td></tr>
<tr><td rowspan="5">Gas and LPG</td><td>Small</td><td>all</td><td>30 (110)</td></tr>
<tr><td rowspan="2">Medium</td><td>0 or 1</td><td>40 (150)</td></tr>
<tr><td>2 or more</td><td>50 (190)</td></tr>
<tr><td rowspan="2">Large</td><td>0 to 2</td><td>50 (190)</td></tr>
<tr><td>3 or more</td><td>75 (280)</td></tr>
<tr><td rowspan="3">Oil</td><td>Small</td><td>all</td><td rowspan="2">32 (120)</td></tr>
<tr><td>Medium</td><td>all</td></tr>
<tr><td>Large</td><td>all</td><td>50 (190)</td></tr>
</table>

Terms and values for no_dw, no_cw, senior_mf, and no_pay were developed by Lawrence Berkeley National Laboratory (LBNL) for the draw model.[8] Standard errors for the coefficients used in the hot water draw equation were reported in the hot water consumption model described in the study prepared for EPRI.[9] We used these values to specify the normal distributions for the coefficients.

9.2.5 Results of Hot Water Use Calculations

Figure 9.2.1 shows a histogram of estimated daily hot water use for households with electric, natural gas, LPG, and oil-fired water heaters. For households with electric water heaters, average daily use is 45.3 gallons. For households with natural gas water heaters, the average daily use is 49.9 gallons of hot water. For households with water heaters fueled with LPG, the average daily use is 45.7 gallons of hot water. For oil-fired households, the average daily use is 47.3 gallons of hot water.

These differences in water use are due primarily to the number of people in the different households. The same equation for hot water use is applied to all households, regardless of water heater fuel type.

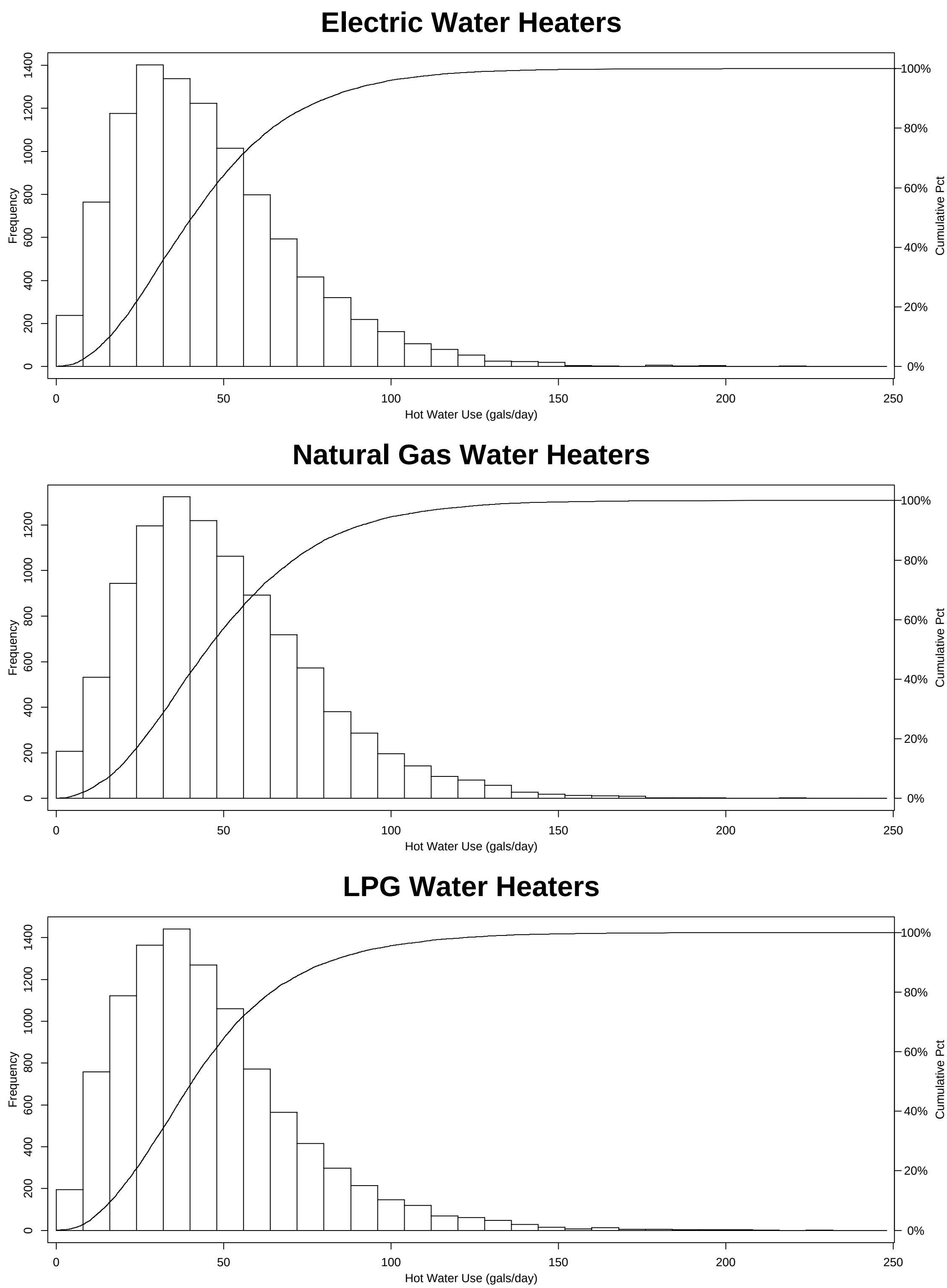

Figure 9.2.1 Frequency Charts of Hot Water Use

9.2.6 Importance Analysis

The following four charts, Figures 9.2.2 through 9.2.5, show the results of the importance analysis for differences in household hot water use at Trial Standard Level 3 for electric, natural gas, LPG, and oil-fired water heaters. Figure 9.2.2 shows the rank-order correlation of input variables with hot water use for electric water heaters. Figures 9.2.3 and 9.2.4 show the same for 78% RE and 2" Insulation for natural gas and LPG water heaters, respectively. Figure 9.2.5 shows the rank-order correlation of input variables for the 2003 Baseline oil-fired water heaters. Variables are ordered with maximum correlation coefficients (positive or negative) on top and minimum coefficients on the bottom.

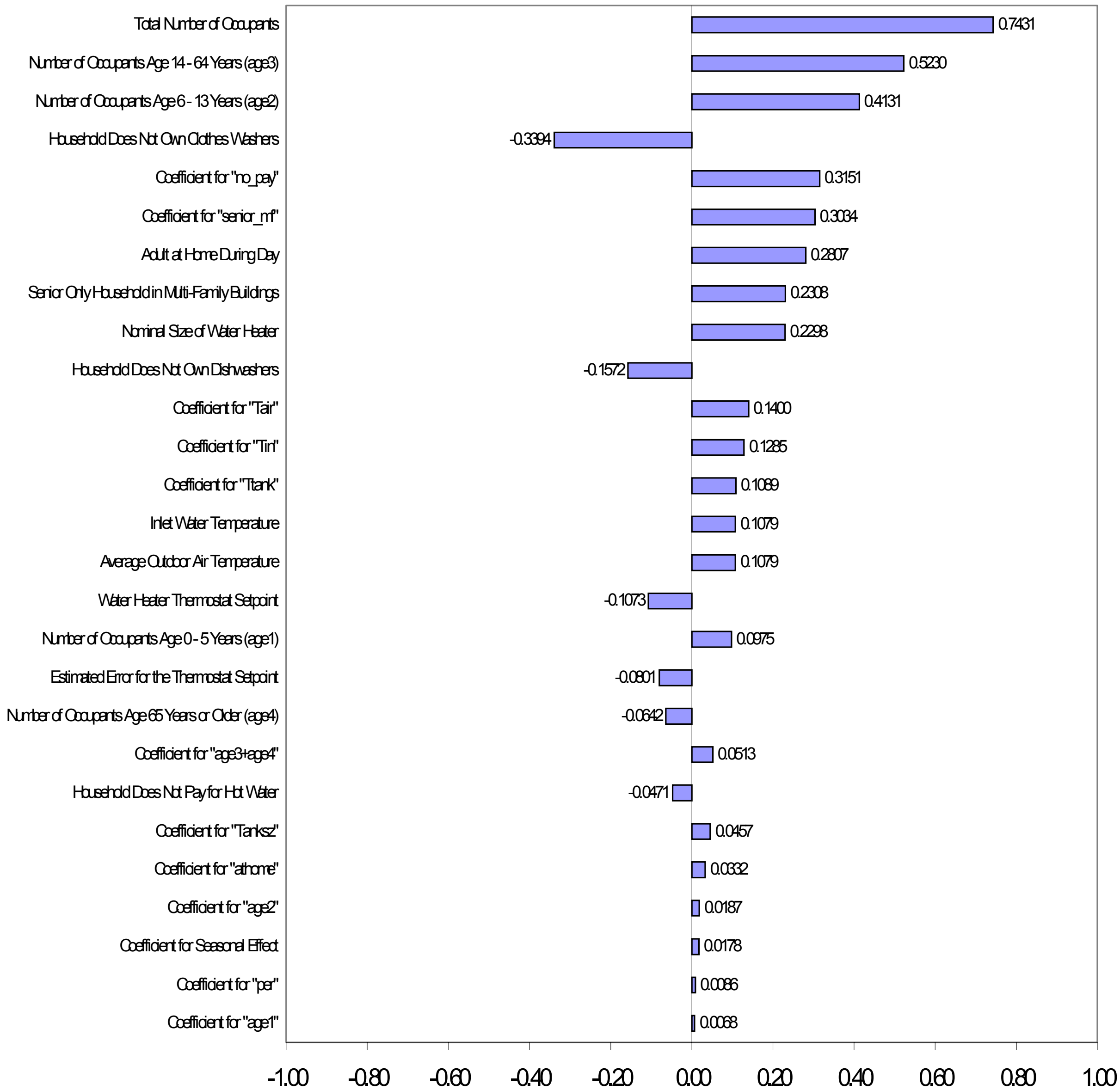

Figure 9.2.2 Importance of Input Variables to Hot Water Use for Electric Water Heaters

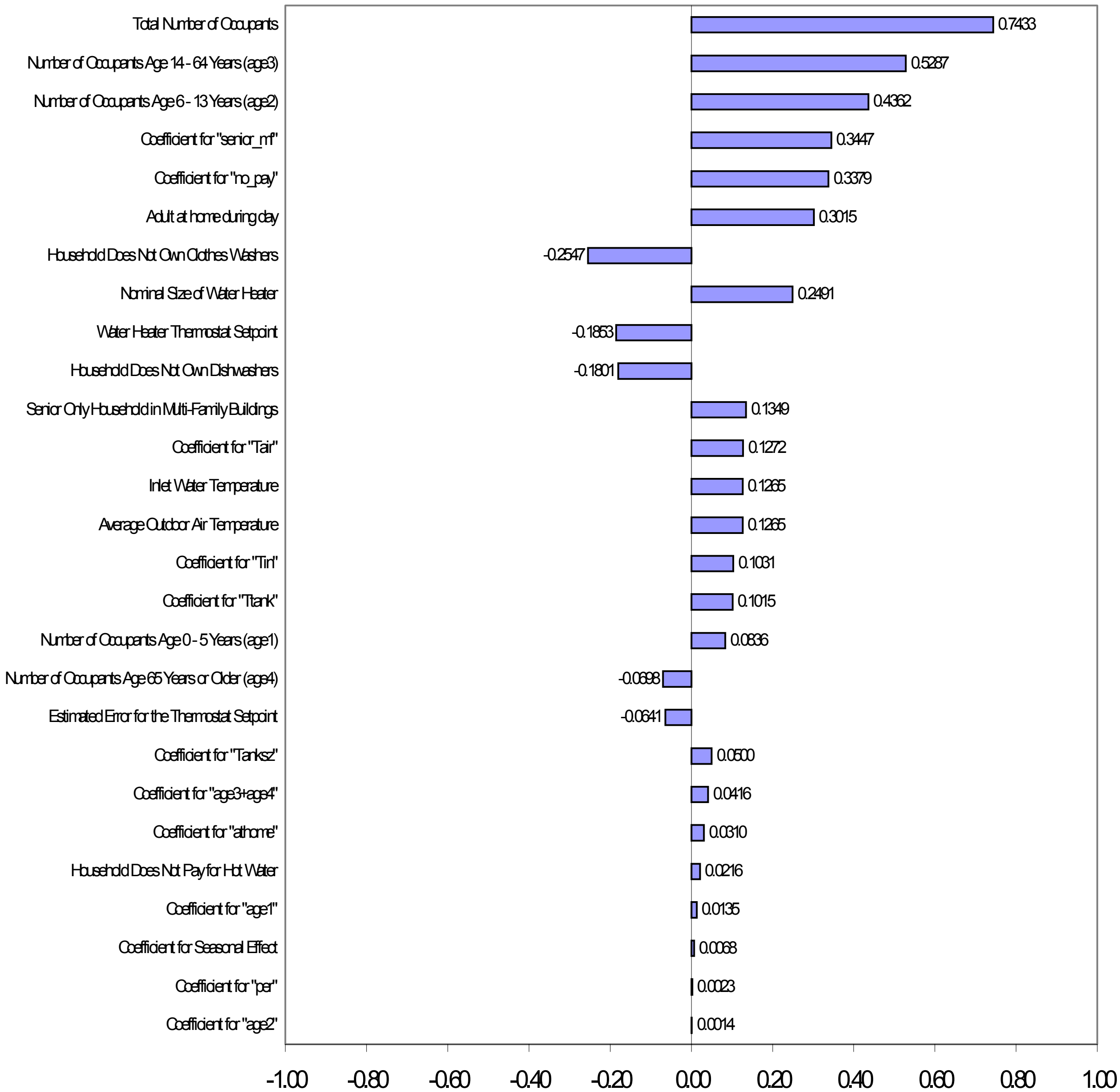

Figure 9.2.3 Importance of Input Variables to Hot Water Use for Natural Gas Water Heaters

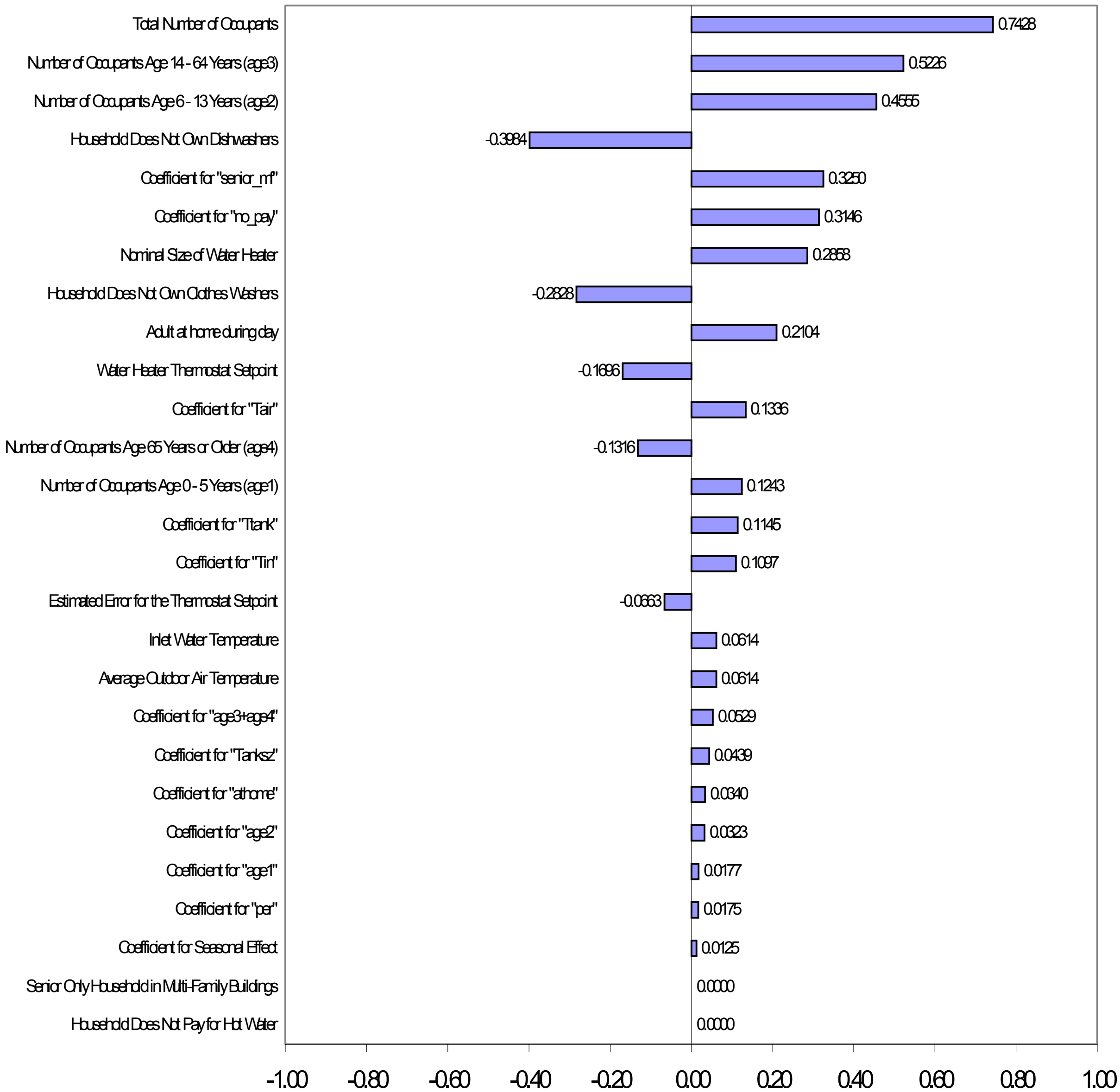

Figure 9.2.4 Importance of Input Variables to Hot Water Use for LPG Water Heaters

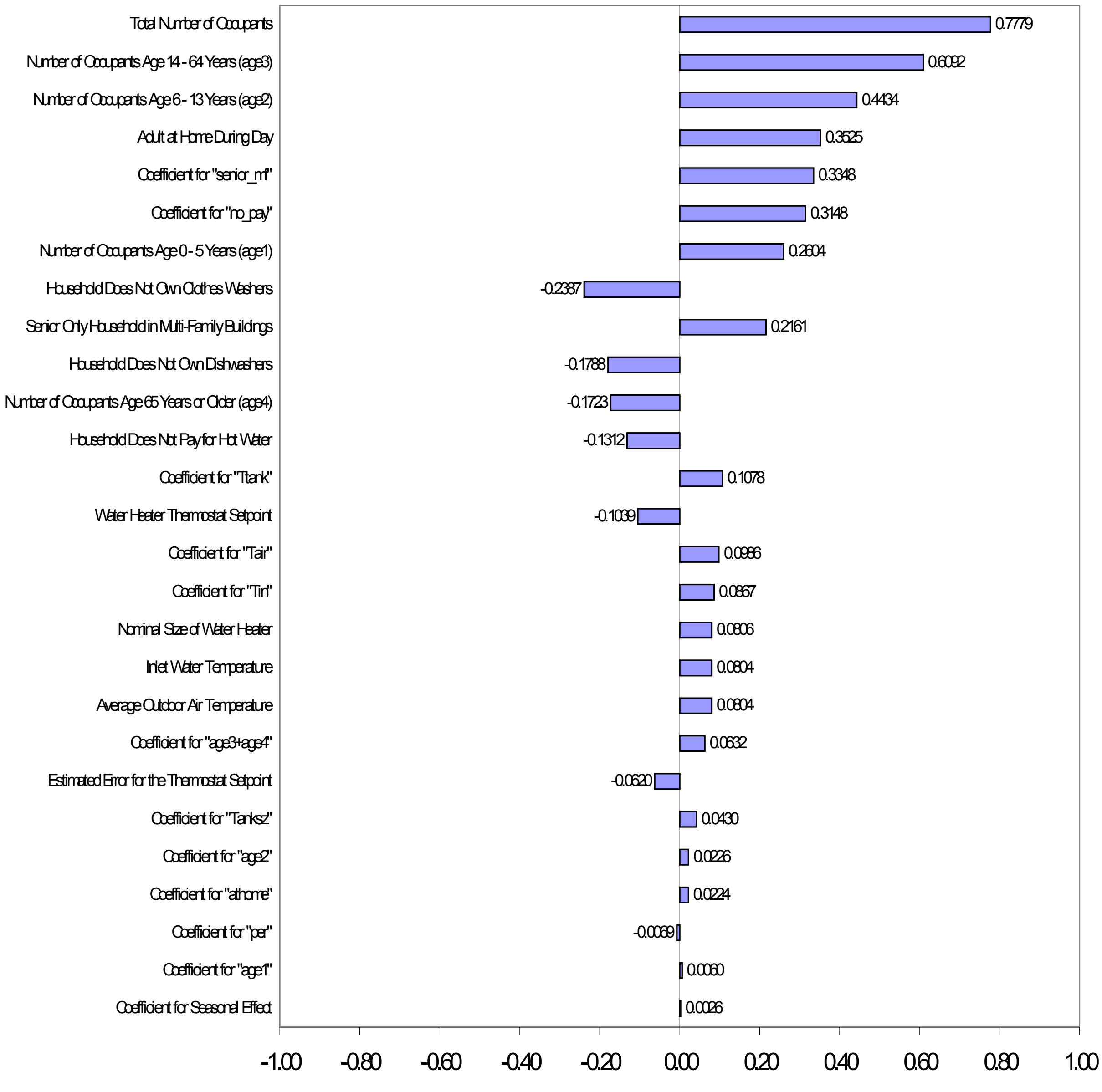

Figure 9.2.5 Importance of Input Variables to Hot Water Use for Oil-Fired Water Heaters

9.3 ENERGY ANALYSIS MODULE

9.3.1 Introduction to Energy Use

Residential water heater energy usage is accurately estimated, within 3% to 5% compared to TANK or WATSIM, using a simplified energy equation, the Water Heater Analysis Model (WHAM).[10, 11] WHAM accounts for a variety of operating conditions and water heater characteristics. WHAM uses three parameters—recovery efficiency (RE), standby heat-loss coefficient (UA), and rated input power (Pon)—to describe water heater efficiency characteristics. Water heater operating conditions are indicated by average daily hot water draw volume, inlet water temperature, thermostat setting, and air temperature around the water heater.

WHAM was developed to quickly and reliably estimate residential water heater energy consumption. Because it is written as an equation, WHAM can be used in spreadsheets. It does not require the detailed inputs that other water heater simulation models demand. In each of the LCC analysis spreadsheets, water heater energy consumption is calculated for 10,000 different household samples for existing and 2003 baseline water heaters and all design options being considered. (Please refer to Section 9.1 for a definition of the 2003 baseline and design options.) We used WHAM in conjunction with Crystal Ball to calculate water heater energy consumption.

The energy analysis module uses the average daily hot water consumption for all sampled households, as calculated by the Hot Water Draw Module. Other key characteristics, such as water temperature for each household, are derived from the RECS database.[1] The LCC analysis uses RE and UA values from computer simulations developed for the Engineering Analysis (see Chapter 8) and Pon from manufacturers' product literature to describe the energy performance of water heaters.

9.3.2 Equation for Energy Use

The WHAM equation solves for average daily water heater energy consumption (Q_{in}), and is expressed as follows:

$$Q_{in} = \frac{vol \cdot den \cdot C_p \cdot \left(T_{tank} - T_{in}\right)}{RE} \cdot \left(1 - \frac{UA \cdot \left(T_{tank} - T_{amb}\right)}{Pon}\right) + 24 \cdot UA \cdot \left(T_{tank} - T_{amb}\right)$$

where:

Q_{in} = total water heater energy consumption (Btu/day)

RE = recovery efficiency

Pon = rated input power (Btu/hr)

UA = standby heat-loss coefficient (Btu/hr-°F)

T_{tank} = thermostat setpoint temperature (°F)

T_{in} = inlet water temperature (°F)

T_{amb} = temperature of the air surrounding the water heater (°F)

vol = volume of hot water drawn in 24 hours (gal/day)

den = density of stored water, set constant at 8.29 lb/gal

Cp = specific heat of stored water, set constant at 1.000743 Btu/lb-°F

9.3.3 General Description of Key Variables

Recovery Efficiency (RE). The recovery efficiency (RE) is the ratio of energy added to the water compared to the energy input to the water heater. It represents how efficiently energy is transferred to the water when the heating element is on or the burner is firing. RE covers steady-state efficiency only. It accounts for the amount of energy lost through the water heater jacket and the flue and fittings while the heater is firing.

Rated Input Power (Pon). Rated input power is the nominal power rating the manufacturer assigns to a particular design of water heater expressed in kW for electric water heaters or Btu/hr for gas-fired (both natural gas and LPG)[a] or oil-fired water heaters. For gas-fired water heaters this includes the pilot light.

Standby Heat-Loss Coefficient (UA). The standby heat loss coefficient (UA) indicates the water heater hourly standby energy losses, expressed in Btu/hr-°F. UA is reported in terms of energy input required to maintain the water at the setpoint temperature. This represents the rate at which energy must be added to the water heater when it is not heating water for delivery.

Thermostat Setpoint Temperature (T_{tank}). The thermostat setpoint temperature is the desired delivery temperature of the hot water.

Inlet Water Temperature (T_{in}). The inlet water temperature is the temperature of the water supplied to the water heater.

[a] Water heaters fueled by natural gas and LPG are considered as one product class from the point of view of physical and efficiency characteristics. They are treated separately with respect to manufacturing cost, markup, retail price, and fuel price in the Life-Cycle Cost and subsequent analyses.

Temperature of the Air Surrounding the Water Heater (T_{amb}). The temperature surrounding the water heater is the ambient air temperature of the space where the water heater is located.

Volume of Hot Water Drawn in 24-Hour Period (vol). This is the estimated daily household use of hot water. It is calculated in the Hot Water Draw Model.

Density of Water (den). This is the density of hot water at the average of the setpoint and inlet temperatures (8.29 lb/gal). It is mass per unit volume, expressed as lb/gal (kg/l).

Specific Heat of Water (C_p). This represents the specific heat of water at the average of the setpoint and inlet temperatures (1.000743 Btu/lb-°F). This is the amount of heat needed to increase or decrease the temperature of 1 pound mass of water by 1 °F (1 kJ/kg - K).

9.3.4 General Description of Data Sources

9.3.4.1 Derivations of Energy Parameters

Introduction. We calculated total water heater energy consumption (Q_{in}) using water heater energy parameters including the recovery efficiency (RE), the standby heat loss coefficient (UA), the rated input power (Pon), and the estimated hot water use. The definitions for the water heater energy parameters are provided by the U.S. DOE Energy Factor (EF) test procedure for water heaters.[12] We developed the energy parameters using simulation models and customized calculation tools created at LBNL, information from water heater manufacturer and retail contacts, and independent sources.

Determining RE, UA, and Pon. The LCC analysis uses RE and UA values from computer simulations developed for the Engineering Analysis (Chapter 8). We used the WATSIM water heating simulation program for electric water heaters, the TANK simulation program for gas-fired water heaters (both natural gas and LPG), and WHAM for oil-fired water heaters.

WATSIM is a detailed electric water heater simulation program developed by EPRI.[13] The use of WATSIM is explained in the Engineering Analysis. WATSIM does not directly provide values for RE and UA. It does, however, provide detailed temperature profiles of water inside the water heater tank during the simulation run. These temperature readings can be used to determine the energy parameters of an electric water heater using standard test procedure calculations. We developed a spreadsheet tool, described in Appendix D-1, to calculate RE and UA.

TANK is a detailed gas-fired storage water heater simulation program developed by Battelle for the Gas Research Institute.[14] TANK is described in Chapter 8. The outputs of TANK include RE and UA.

We used the simplified water heater model WHAM to analyze oil-fired water heaters. For oil-fired water heaters, we calculated total daily energy consumption based on estimated burner operating hours and then used a rearranged WHAM equation to estimate UA. The use of the WHAM model for calculation of energy parameters for oil-fired water heaters is also explained in Chapter 8.

The primary data source for rated input power (Pon) is water heater manufacturers' product literature. In order to generate Pon values, we examined a large sample of water heaters and assigned typical values for all standard water heater sizes analyzed in the LCC. Table 9.3.1 is a summary of all standard water heater sizes studied in this analysis with corresponding values for UA, RE, and Pon for the four fuel types.

Table 9.3.1 Water Heater Design Characteristic Values

	Rated Volume *gal/liter*	**UA** *Btu/hr-°F*	**RE**	**Pon** *Btu/hr*
Electric	30 (110)	2.92	0.972	15,354
	40 (150)	3.40	0.968	15,354
	50 (190)	3.64	0.967	15,354
	65 (250)	3.98	0.966	15,354
	80 (300)	4.42	0.965	15,354
Natural Gas and LPG	30 (110)	11.56	0.758	30,000
	40 (150)	13.86	0.756	40,000
	50 (190)	16.14	0.723	50,000
	75 (280)	21.80	0.672	75,000
Oil-Fired	32 (120)	14.93	0.760	90,000
	50 (190)	18.26	0.760	104,000

Water Heater Sizes. When we refer to "typical" water heater sizes, we mean the most common water heater size for each fuel type, with an energy factor at the minimum allowed by current energy-efficiency standards. These units have the largest market share in their product class (50-gal/190 liter for electric, 40-gal/150 liter for natural gas and LPG, and 32-gal/120 liter for oil-fired). We used "typical" sizes in the Engineering Analysis, so all data from that analysis are for only these three sizes. However, for the purposes of the LCC analysis, we expanded the range of sizes considered to include all those listed in Table 9.2.1 so that our analysis would accurately reflect the broad range of water heater sizes and thus LCCs that consumers are likely to encounter. This expanded repertoire of sizes is referred to as "standard" sizes and appears in Table 9.3.1 as well as Table 9.2.1.

We had to derive data for standard sizes using data for typical sizes. We derived all standard-size 2003 baseline models by adjusting the typical 2003 baseline models in the WATSIM and TANK simulation tools. Table 9.3.2 shows the values of the electric water heater parameters that were adjusted in WATSIM in order to model the standard tank sizes. We determined the typical tank diameter for each standard size from a large sample of water heaters selected from the product literature. The actual tank volume of an electric water heater is 10% less than the rated volume. We used the values for tank diameter and actual tank volume to calculate tank height. We determined the rest of the geometry parameters, such as the locations of the hot and cold water outlets, the electric heater elements, the thermostats, and the miscellaneous feed-through fittings, by scaling relative to the length of the baseline model.[a] In WATSIM, all heights are referenced from the bottom of the tank support skirt (top of the base pad).

Table 9.3.2 Electric Water Heater Modeling Parameter Variations

	30-gal	40-gal	50-gal	65-gal	80-gal
Tank Diameter (ft)	1.17	1.17	1.32	1.50	1.67
Tank Height (ft)	3.48	4.60	4.54	4.55	4.52
Location of H.W. Inlet (ft)	3.48	4.60	4.54	4.55	4.52
Height of Heater Element 1 (ft)	0.48	0.63	0.62	0.62	0.60
Height of Heater Element 2 (ft)	2.48	3.28	3.24	3.25	3.23
Height of Thermostat 1 (ft)	0.70	1.01	1.00	1.00	1.00
Height of Thermostat 2 (ft)	2.79	3.69	3.64	3.65	3.62
Height of Feed-Through 1 (ft)	3.48	4.60	4.54	4.55	4.52
Height of Feed-Through 2 (ft)	3.48	4.60	4.54	4.55	4.52
Height of Feed-Through 3 (ft)	0.13	0.13	0.13	0.13	0.13
Height of Feed-Through 4 (ft)	3.48	4.60	4.54	4.55	4.52

Table 9.3.3 shows the values of the gas-fired (both natural gas and LPG)[b] water heater parameters that were adjusted in TANK to model all the standard tank sizes. We determined all of the required TANK input parameters, such as tank diameter, internal flue diameter, and firing rate for each standard size, from a large sample of water heaters selected from product literature. The actual tank volume of a gas-fired water heater is 5% less than the rated volume. The TANK simulation program calculates most of the geometry parameters based on values for tank diameter and volume. The location (elevation) of the thermostat does not change from size to size; it is fixed at a height of 0.39 feet (11.9 cm). TANK requires an input for the "Volume to Thermostat (gal)" parameter, which is the amount of water that would need to be added to an empty water heater tank

[a] The height of the lower element and thermostat and the drain (feed-throughs) are kept constant across all tank sizes to reflect standard manufacturing practice.

[b] Water heaters fueled by natural gas and LPG are considered as one product class from the point of view of physical and efficiency characteristics. They are treated separately with respect to manufacturing cost, markup, retail price, and fuel price in the Life-Cycle Cost and subsequent analyses.

to raise the water level to the thermostat location. We determined this parameter using the specific tank diameter and the thermostat elevation.

Table 9.3.3 Natural Gas and LPG Water Heater Modeling Parameter Variations

	30-gal	40-gal	50-gal	75-gal
Tank Volume (gal)	28.5	38.0	47.5	71.2
Firing Rate (Btu/hr)	30,000	40,000	50,000	75,000
Tank Diameter (in)	13.84	15.84	17.84	21.84
Internal Flue Diameter (in)	2.84	3.84	3.84	3.84
Volume to Thermostat (gal)	3.1	4.05	6.36	7.70

We performed detailed computer simulations for each design option and all combinations of design options as they applied to all of the standard-size 2003 baseline models.

Table 9.3.4 shows the values of the oil-fired water heater parameters that were adjusted in WHAM to model the 50-gal standard tank size.

Table 9.3.4 Oil-Fired Water Heater Modeling Parameter Variations

	32-gal	50-gal
Tank Volume (gal)	30.5	47.5
Firing Rate (Btu/hr)	90,000	105,000
Tank Diameter (in)	17.84	19.84
Tank Height (in)*	29.6	41.0
Burner Power Draw (W)	282	282

*Tank height measured along outside tank wall.

Determination of Uncertainty Ranges for EF, RE, UA, and Pon. The energy factor (EF) is the ratio of output energy in the form of hot water to the input energy at the standard test conditions. We use the WHAM equation in the LCC analysis to calculate energy consumption for all design options as a function of RE, UA, and Pon, which are calculated as explained at the beginning of this section.

We developed a procedure to calculate uncertainty ranges for all the energy parameters. A consultant provided an estimate of the EF values and the associated uncertainty ranges for all design options added separately to typical existing baseline electric and gas water heaters.[15]

We used the EF uncertainty range data for the typical tank sizes to develop ratios that present the variations of the EF values for all the standard tank sizes.

We developed the range of uncertainty for RE and UA from the range of uncertainty for EF. We calculated variations in RE and UA that would independently cause the desired variation of EF, and reduced the range of the RE and UA terms by 1/%2. This adjustment assumes that the RE and UA distributions have approximately equal impacts on EF. A detailed explanation of the entire procedure to develop the uncertainties for the water heater energy parameters is found in Appendix E-2. Variations in Pon have a much smaller impact on EF within the operating limits of actual water heaters. The variations in Pon for each standard size are from water heaters listed in the Gas Appliance Manufacturers Association (GAMA) directory.[16]

The impact on EF for variations in RE, UA, and Pon are shown in Table 9.3.5 for electric, in Table 9.3.6 for natural gas and LPG, and in Table 9.3.7 for oil-fired water heaters.

Table 9.3.5 Energy Efficiency Characteristics for Electric Water Heaters (50-gal)

Design Options	EF_{WHAM}	EF_{min}	EF_{max}	RE	RE_{min}	RE_{max}	UA	UA_{min} *Btu/hr-°F*	UA_{max}	Pon	Pon_{min} *Btu/hr*	Pon_{max}
Existing Baseline(141b)	0.8714	0.8627	0.8801	0.9800	0.9721	0.9879	3.6401	3.4102	3.8748	15354	12966	18766
2003 Baseline (245fa)	0.8715	0.8627	0.8802	0.9800	0.9721	0.9879	3.6379	3.4079	3.8725	15354	12966	18766
Heat Traps	0.8814	0.8703	0.8924	0.9800	0.9702	0.9898	3.2962	2.9857	3.5599	15354	12966	18766
Tank Bottom Insulation	0.8860	0.8727	0.8993	0.9800	0.9684	0.9917	3.0979	2.7603	3.4457	15354	12966	18766
2" Insulation	0.8980	0.8801	0.9160	0.9800	0.9647	0.9953	2.6656	2.2237	3.1256	15354	12966	18766
2.5" Insulation	0.9077	0.8851	0.9304	0.9800	0.9611	0.9989	2.3248	1.7810	2.8965	15354	12966	18766
Plastic Tank	0.9109	0.8836	0.9382	0.9800	0.9575	1.0026	2.2162	1.5691	2.9035	15354	12966	18766
3" Insulation	0.9177	0.8901	0.9452	0.9800	0.9577	1.0024	1.9841	1.3417	2.6663	15354	12966	18766

Table 9.3.6 Energy Efficiency Characteristics for Natural Gas and LPG Water Heaters (40-gal)

Design Options	EF_{WHAM}	EF_{min}	EF_{max}	RE	RE_{min}	RE_{max}	UA	UA_{min} *Btu/hr-NF*	UA_{max}	Pon	Pon_{min} *Btu/hr*	Pon_{max}
Existing Baseline (141b)	0.5431	0.5377	0.5485	0.7571	0.7495	0.7648	13.9930	13.6464	14.3466	40000	28000	60000
2003 Baseline (245fa)	0.5429	0.5375	0.5483	0.7572	0.7496	0.7649	14.0170	13.6703	14.3707	40000	28000	60000
Heat Traps	0.5519	0.5450	0.5588	0.7561	0.7468	0.7655	13.1550	12.7297	13.5911	40000	28000	60000
78% RE	0.5643	0.5530	0.5756	0.7717	0.7566	0.7871	12.7880	12.1282	13.4748	40000	28000	60000
78% RE, 2" Insulation	0.5922	0.5744	0.6100	0.7799	0.7579	0.8023	10.9070	9.9736	11.8981	40000	28000	60000
78% RE, 2.5" Insulation	0.5982	0.5773	0.6192	0.7818	0.7564	0.8078	10.5340	9.4613	11.6845	40000	28000	60000
80% RE, 2" Insulation	0.6080	0.5867	0.6292	0.8002	0.7740	0.8271	10.5900	9.5359	11.7205	40000	28000	60000
80% RE, 2.5" Insulation	0.6145	0.5914	0.6375	0.8022	0.7743	0.8308	10.2050	9.0904	11.4064	40000	28000	60000
80% RE, 3" Insulation	0.6185	0.5922	0.6448	0.8027	0.7713	0.8350	9.9400	8.6912	11.2997	40000	28000	60000
Side Arm	0.7149	0.6809	0.7488	0.8000	0.7699	0.8305	3.9894	2.7873	5.3114	40000	28000	60000

Table 9.3.7 Energy Efficiency Characteristics for Oil-Fired Water Heaters (32-gal)

Design Options	EF_{WHAM}	EF_{min}	EF_{max}	RE	RE_{min}	RE_{max}	UA	UA_{min} *Btu/hr-NF*	UA_{max}	Pon	Pon_{min} *Btu/hr*	Pon_{max}
Existing Baseline (141b)	0.5290	0.5184	0.5396	0.7500	0.7349	0.7653	14.4935	13.8143	15.2064	90000	84000	105000
2003 Baseline (245fa)	0.5290	0.5184	0.5396	0.7500	0.7349	0.7653	14.4935	13.8143	15.2064	90000	84000	105000
Heat Traps	0.5350	0.5243	0.5457	0.7500	0.7350	0.7651	13.9435	13.2721	14.6487	90000	84000	105000
2" Insulation	0.5506	0.5396	0.5616	0.7508	0.7362	0.7654	12.5979	11.9451	13.2826	90000	84000	105000
2.5" Insulation	0.5543	0.5432	0.5653	0.7509	0.7365	0.7655	12.2950	11.6464	12.9751	90000	84000	105000
3" Insulation	0.5568	0.5456	0.5679	0.7510	0.7366	0.7656	12.0890	11.4433	12.7660	90000	84000	105000
78% RE	0.5780	0.5665	0.5896	0.7800	0.7650	0.7951	11.6441	11.0227	12.2955	90000	84000	105000
Interrupted Ignition	0.5819	0.5702	0.5935	0.7852	0.7702	0.8004	11.5671	10.9485	12.2127	90000	84000	105000
Increased HX Area	0.6114	0.5992	0.6237	0.8254	0.8096	0.8414	11.0077	10.4197	11.6213	90000	84000	105000

9.3.4.2 Temperature Derivations

The temperatures for water heater thermostat setpoint, inlet water temperature, and temperature of the air surrounding the water heater are based on average annual outside air temperature.

RECS provides data on heating and cooling degree days but not air temperatures for each household in the sample. To assign a physical location to each RECS household from which outside air temperatures could be derived, we took three steps:

1. We used a weather zone classification which divided the continental United States into 841 different weather stations.

2. The National Oceanic and Atmospheric Administration (NOAA) provides daily maximum and minimum air temperatures for all of the 841weather stations.[5] We assumed that the average daily temperature would be the average of the maximum and minimum temperatures. We used the average daily temperature to calculate heating and cooling degree days for each station. Cooling degree days are the number of degrees the average temperature is above a base temperature. Base temperatures of 65, 70 and 75°F were used. Heating degree days are the number of degrees the average temperature is below a base temperature. Base temperatures of 50, 55, 60, 65 and 70°F were used.

3. RECS reports heating degree days to base temperatures 50, 55, 60, 65 and 70°F and cooling degree days to base temperatures 65, 70 and 75°F for each housing record. We assigned each RECS household to one of the 841 weather stations by calculating which weather station (within its reported census region or large state) gave the best linear least squares fit of the RECS data to the NOAA data.

Once each RECS household was associated with a weather station, we made other temperature assignments based on the 30-year average annual temperatures from NOAA.

We assumed inlet water temperature to be the same as groundwater temperature, which varies according to geographic region. Groundwater temperatures are assumed to be slightly warmer than air temperatures. We added two degrees to NOAA average annual outside air temperature data to calculate the inlet water temperature.[17] We compared the estimates to the National Well Water Association's published annual average groundwater temperatures for various regions in the country.[18] The comparison shows that, in the majority of cases, the inlet water temperature averages 2°F warmer than the outside air temperature.

We assigned water heater thermostat settings to RECS households based on their inlet water temperatures and an equation derived from a California Energy Commission (CEC) study.[19] The CEC study examined single-family houses built between 1984 and 1988 to assess the accuracy of the California Title 24 Energy Efficiency Standards modeling assumptions. The study measured hot and cold water temperatures, assuming that hot water temperatures were equal to water heater thermostat setpoints and that cold water temperatures were equal to inlet water temperatures.

The graph of the CEC data displayed in Figure 9.3.1 shows the correlation between thermostat setpoint and inlet water temperature. The data indicate that people with colder inlet water tend to set their water heaters to higher setpoint temperatures. This makes sense: either hotter water or more hot water must be mixed with cold water to have warm water for household use. People are often motivated to increase their hot water thermostat setpoint if they frequently run out of hot water. Because individual households maintain a wide range of thermostat settings, we added a random error with a mean of 0°F and a standard deviation of 13°F to account for this variability.

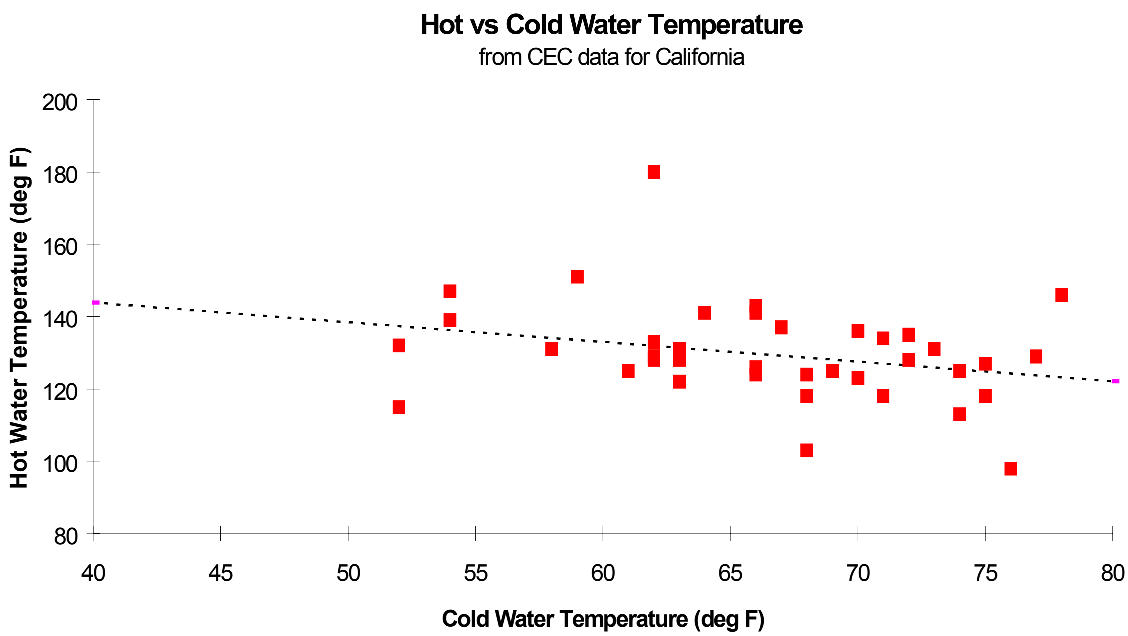

Figure 9.3.1 Comparison of Setpoint and Inlet Water Temperatures

The equation derived from the CEC data is shown below. The equation estimates that, if the inlet water temperature for the household is 58°F, then the water heater's setpoint temperature is 134.1°F. As the inlet water temperature gets warmer, the setpoint temperature decreases.

$$T_{tank} = 134.1 + 0.55 * (58 - T_{in})$$

We developed a set of assumptions to determine air temperature around water heaters based on calls to 50 water heater installers from around the country regarding typical locations for water heater installation.

1. RECS reports the presence or absence of basements in houses and, if there is a basement, whether or not it is heated. If a house had a basement, we assumed that the water heater was located in the basement. For unheated basements, the assigned temperature was the average between the outside air temperature for that weather station and a house air temperature of 72ºF (22.2ºC).

2. If RECS reports the basement as a heated space, then the temperature of the air around the water heater was assumed to be the temperature of the house: 72ºF (22.2ºC).

3. If the house had no basement but did have a garage or carport, we assumed that the water heater was in the garage or carport. The temperature assigned was 5ºF (2.8ºC) higher than the outside air temperature for that house.

4. In the absence of a basement, garage, or carport, it was assumed that the water heater was in the house (in the kitchen or a utility closet), and we assigned a temperature of 72ºF (22.2ºC) to the surrounding air.

Table 9.3.8 shows the percentages of assigned water heater locations.

Table 9.3.8 Water Heater Locations

Water Heater Location	Percentage %
Unheated Basement	6.9
Heated Basement	29.6
Garage	34.3
Inside House	29.2

9.3.5 Energy Analysis Results

9.3.5.1 Electric Water Heater Energy Use

Table 9.3.9 lists average annual energy use for electric water heaters and average daily energy savings for each design option evaluated in the LCC analysis, compared to the 2003 baseline water heater.

Table 9.3.9 Energy Consumption for Electric Water Heaters

Design Option		Average Electricity Use *kWh/yr*	Average Energy Savings *Btu/day*
0	2003 Baseline	3460	
1	Heat Traps	3402	539
2	Tank Bottom Insulation	3382	728
3	2" Insulation	3318	1325
4	2.5" Insulation	3272	1760
5	Plastic Tank	3263	1843
6	3" Insulation	3234	2114

Figure 9.3.2 shows a distribution and cumulative frequency plot of the difference in energy consumption for each design option, compared to 2003 baseline, for electric water heaters. Note that a negative difference in energy consumption for a given design option indicates a savings. The width of the plot shows the spread of savings in the population. In general, the design options with higher efficiencies tend to show a wider spread of energy savings in the population.

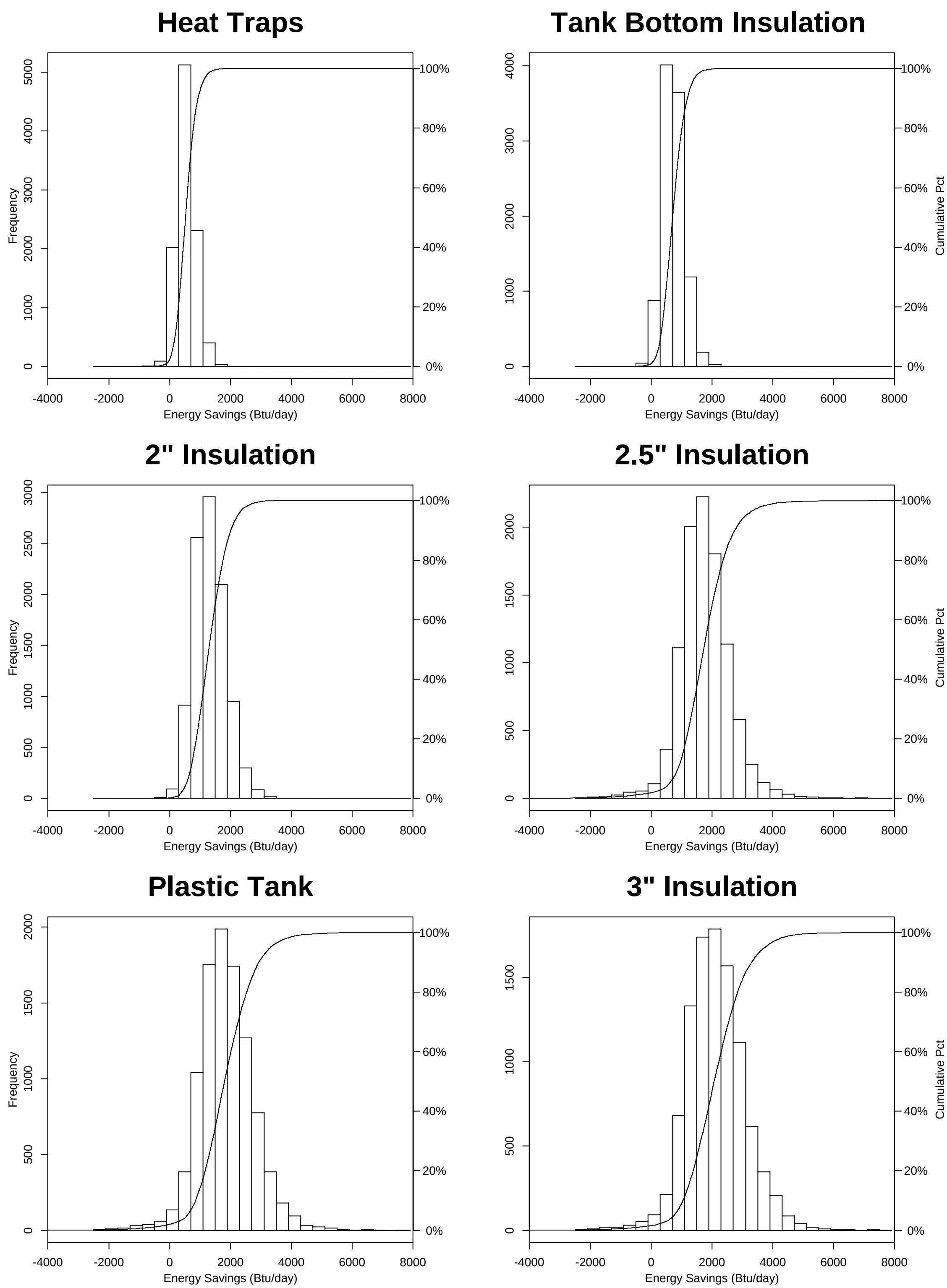

Figure 9.3.2 Differences in Energy Consumption by Design Option for Electric Water Heaters

9.3.5.2 Natural Gas Water Heater Energy Use

Table 9.3.10 lists the average annual energy use for natural gas water heaters and the average daily energy savings for each design option compared to the 2003 baseline water heater.

Table 9.3.10 Energy Consumption for Natural Gas Water Heaters

Design Option		Average Energy Use		Average Energy Savings
		MMBtu/yr	*kWh/yr*	*Btu/day*
0	2003 Baseline	23.4	0.0	–
1	Heat Traps	23.0	0.0	1320
2	78% RE	22.5	0.0	2455
3	78% RE, 2" Insulation	21.2	0.0	5996
4	78% RE, 2.5" Insulation	21.0	0.0	6683
5	80% RE, 2" Insulation	20.7	0.0	7422
6	80% RE, 2.5" Insulation	20.5	0.0	8114
7	80% RE, 3" Insulation	20.3	0.0	8565
8	Side Arm	16.9	21.8	17817

Figure 9.3.3 shows, for each design option, a distribution and cumulative frequency plot of the difference in energy consumption compared to 2003 baseline natural gas water heaters. Note that a negative difference in energy consumption for a given design option indicates a savings. The width of the plot shows the spread of savings in the population. In general, the design options with higher efficiencies tend to show a wider spread of energy savings in the population.

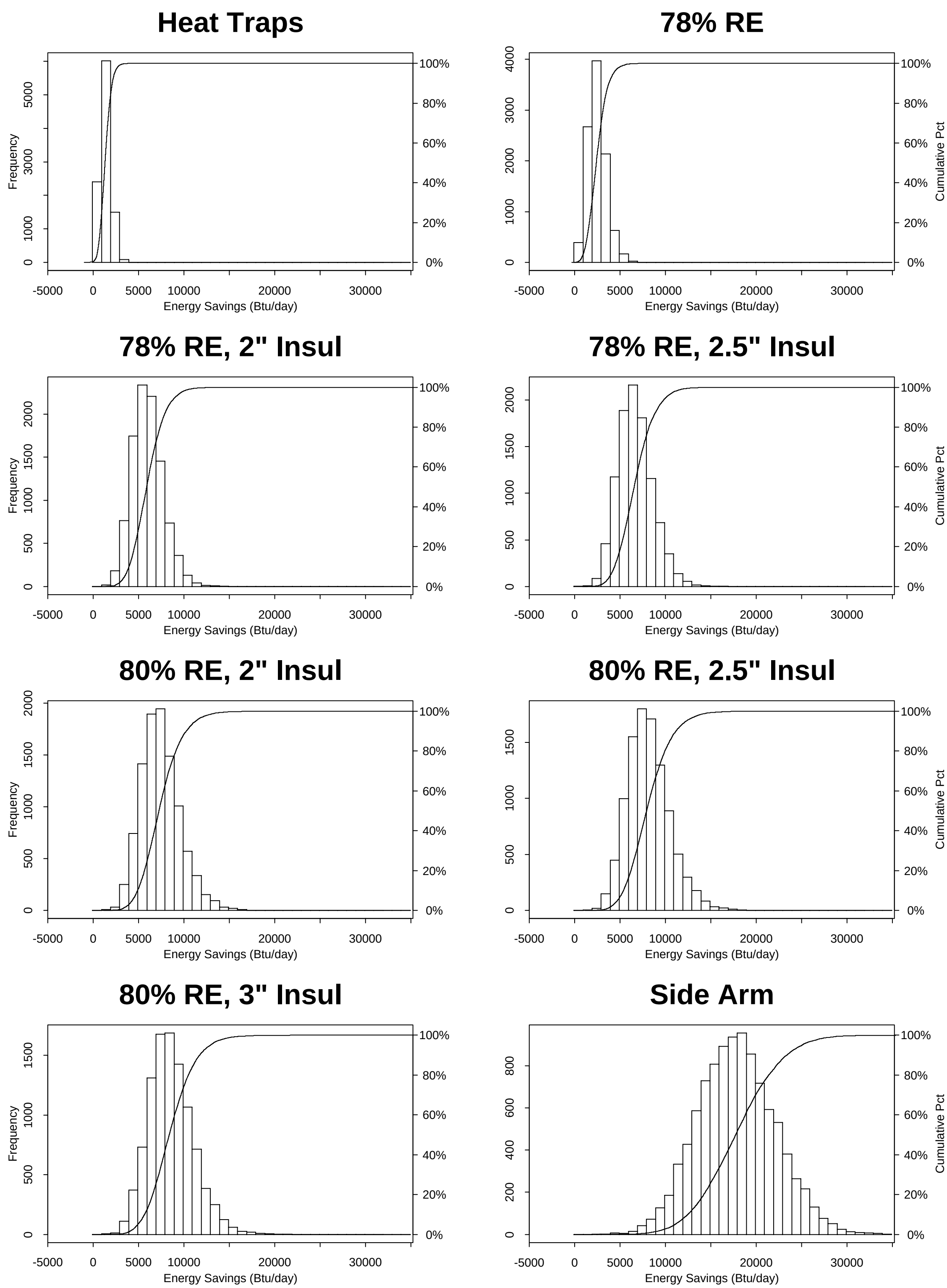

Figure 9.3.3 Differences in Energy Consumption by Design Option for Natural Gas Water Heaters

9.3.5.3 LPG Water Heater Energy Use

Table 9.3.11 lists the average annual energy use for LPG water heaters and the average daily energy savings for each design option compared to the 2003 baseline.

Table 9.3.11 Energy Consumption for LPG Water Heaters

Design Option		Average Energy Use		Average Energy Savings
		MMBtu/yr	*kWh/yr*	*Btu/day*
0	2003 Baseline	22.8	0.0	–
1	Heat Traps	22.3	0.0	1371
2	78% RE	21.9	0.0	2412
3	78% RE, 2" Insulation	20.6	0.0	6005
4	78% RE, 2.5" Insulation	20.4	0.0	6722
5	80% RE, 2" Insulation	20.1	0.0	7429
6	80% RE, 2.5" Insulation	19.9	0.0	8141
7	80% RE, 3" Insulation	19.7	0.0	8570
8	Side Arm	16.2	21.3	18055

Figure 9.3.4 shows, for each design option, a distribution and cumulative frequency plot of the difference in energy consumption compared to 2003 baseline LPG water heaters. Note that a negative difference in energy consumption for a given design option indicates a savings. The width of the plot shows the spread of savings in the population. In general, the design options with higher efficiencies tend to show a wider spread of energy savings in the population.

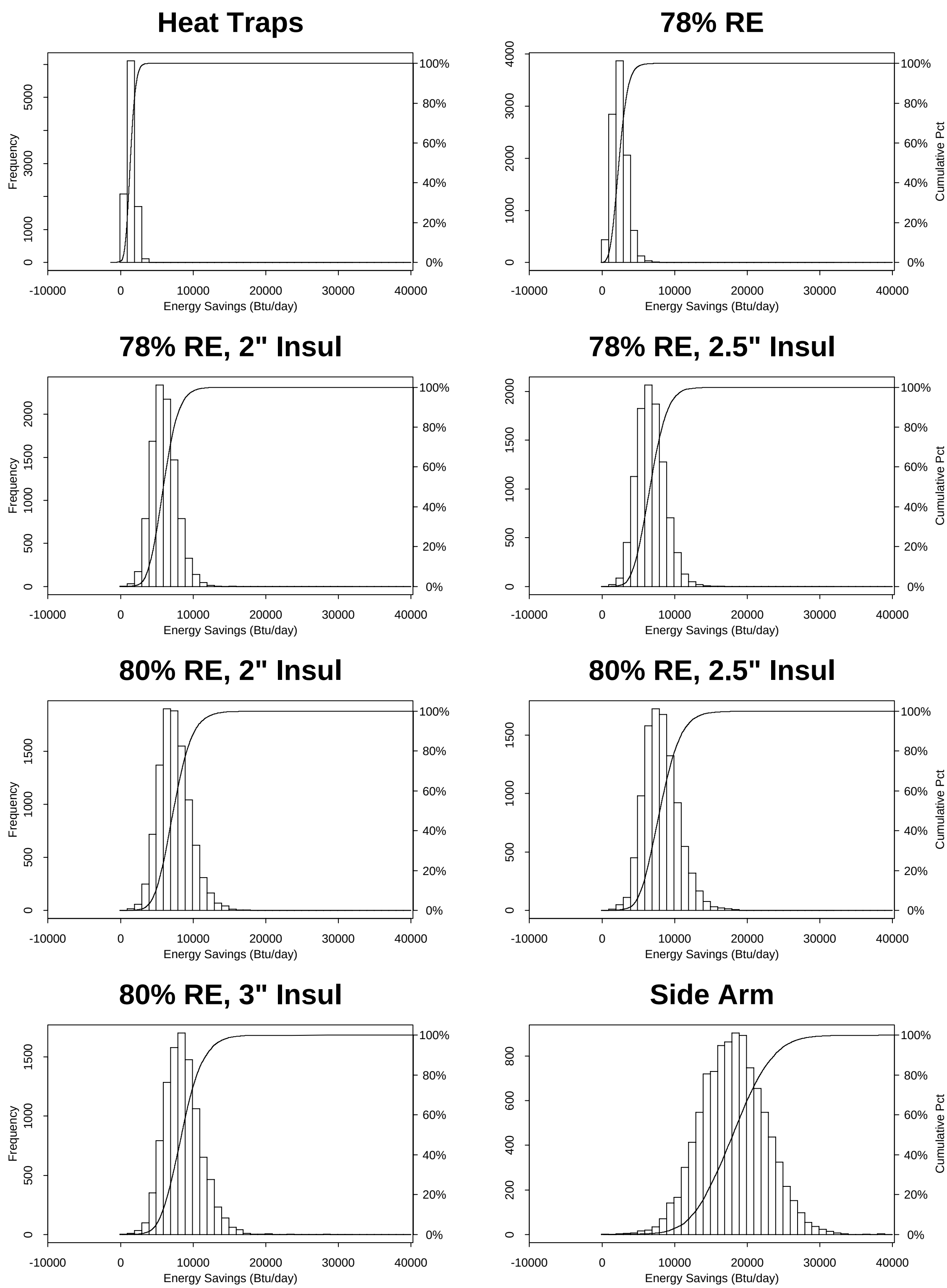

Figure 9.3.4 Differences in Energy Consumption by Design Option for LPG Water Heaters

9.3.5.4 Oil-Fired Water Heater Energy Use

Table 9.3.12 lists the average annual energy use for oil-fired water heaters and the average daily energy savings for each design option compared to the 2003 baseline.

Table 9.3.12 Energy Consumption for Oil-Fired Water Heaters

Design Option		Average Energy Use		Average Energy Savings
		MMBtu/yr	***kWh/yr***	***Btu/day***
0	2003 Baseline	25.4	75.1	–
1	Heat Traps	25.1	74.1	933
2	2" Insulation	24.2	71.5	3409
3	2.5" Insulation	24.0	70.9	3975
4	3" Insulation	23.9	70.5	4352
5	78% RE	23.0	67.9	6782
6	Interrupted Ignition	23.0	25.5	7188
7	Increased HX Area	21.9	24.4	10244

Figure 9.3.5 shows, for each design option, a distribution and cumulative frequency plot of the difference in energy consumption compared to 2003 baseline oil-fired water heaters. Note that a negative difference in energy consumption for a given design option indicates a savings. The width of the plot shows the spread of savings in the population. In general, the design options with higher efficiencies tend to show a wider spread of energy savings in the population.

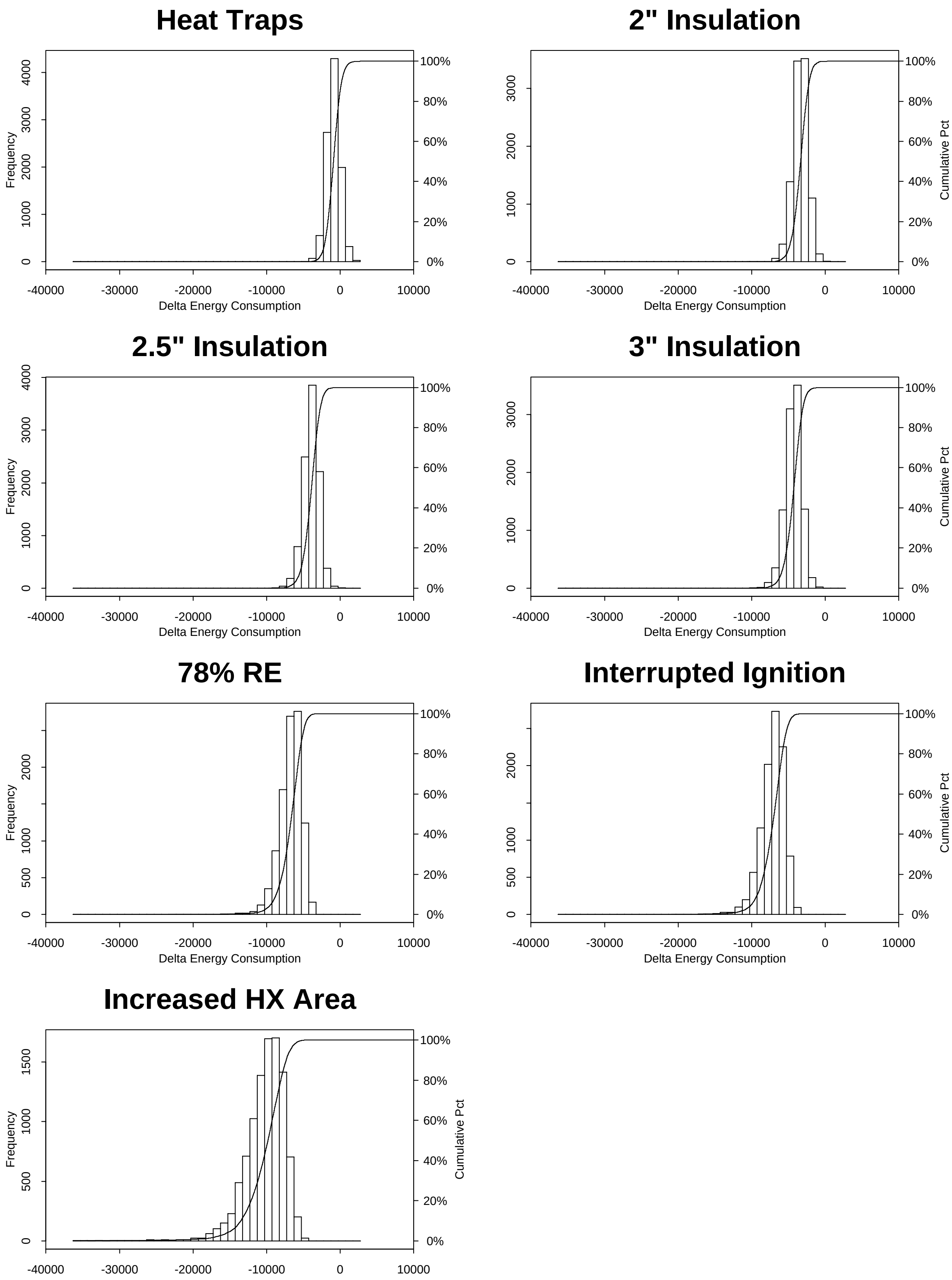

Figure 9.3.5 Differences in Energy Consumption by Design Option for Oil-Fired Water Heaters

9.3.6 Importance Analysis

The following four charts (Figures 9.3.6, 9.3.7, 9.3.8, and 9.3.9) show the results of the importance analysis for energy consumption at Trial Standard Level 3 for electric, natural gas, LPG, and oil-fired water heaters. Figure 9.3.6 shows the rank-order correlation of input variables with energy consumption for the 2.5" Insulation design option on electric water heaters. Figures 9.3.7 and 9.3.8 show the same for 78% RE and 2" Insulation on natural gas and LPG water heaters, respectively. Figure 9.3.9 shows the rank-order correlation for 2003 Baseline on oil-fired water heaters. Variables are ordered with maximum correlation coefficients, positive or negative, on top and minimum coefficients on the bottom. For three types of water heaters (electric, natural gas, and LPG), hot water use has the most significant impact on energy consumption, followed by standby heat loss coefficient. For the natural gas-fired and oil-fired water heaters, rated input power was almost as significant as the standby heat loss coefficient. The most significant impact on energy consumption for oil-fired water heaters was the annual electricity consumption of the 2003 baseline water heater, followed by the hot water use.

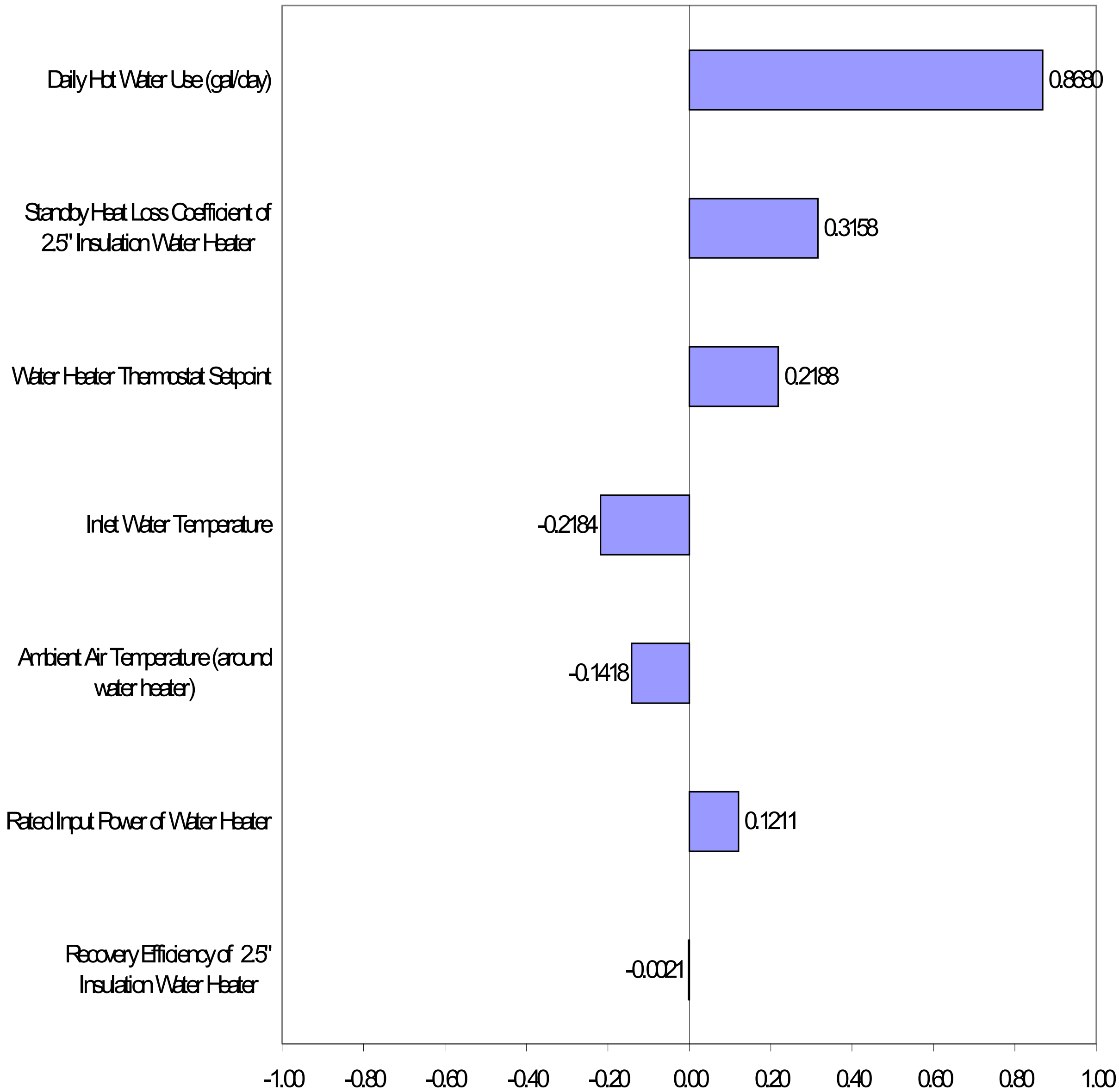

Figure 9.3.6 Importance of Input Parameters to Annual Energy Consumption for 2.5" Insulation on Electric Water Heaters

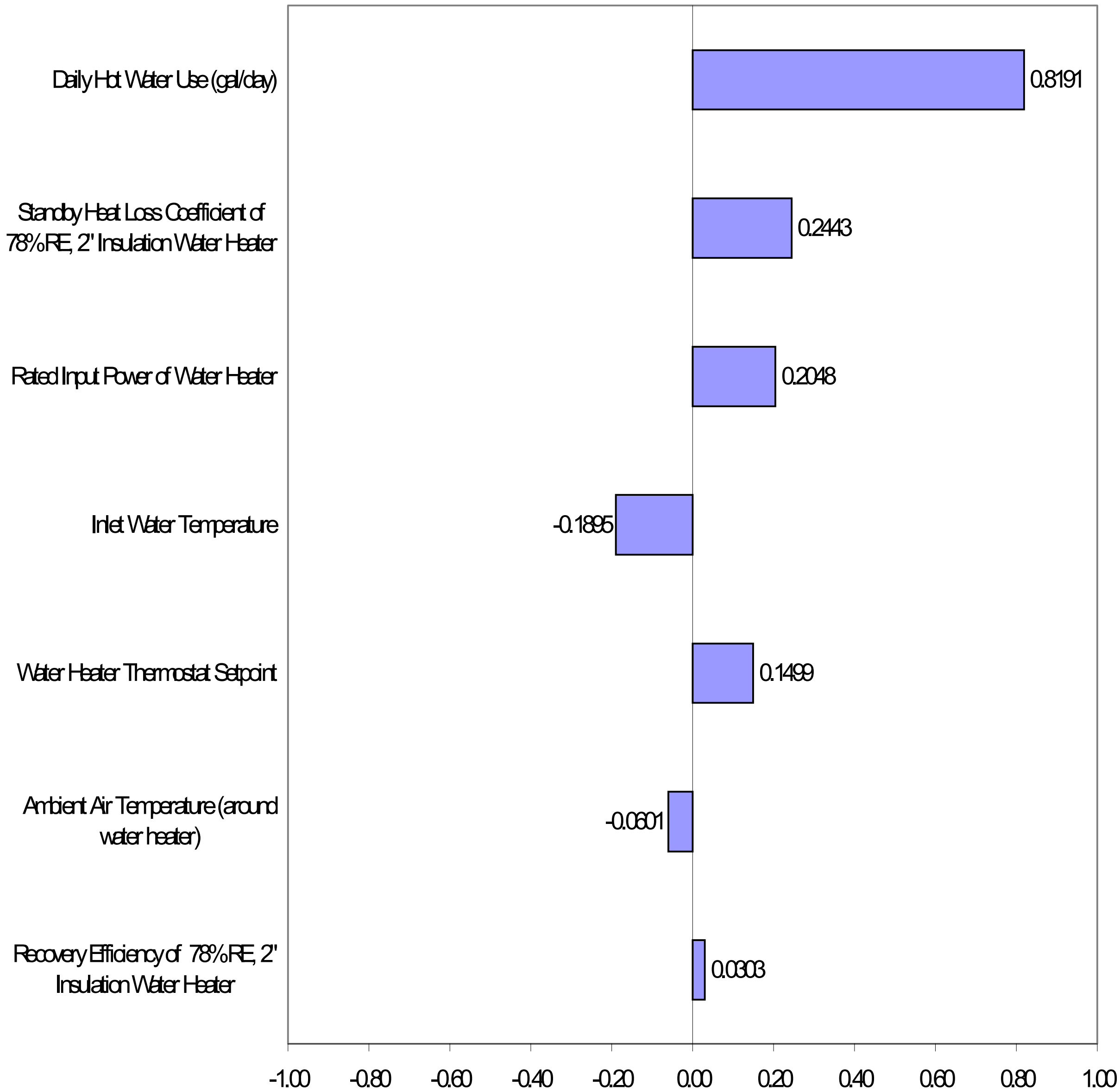

Figure 9.3.7 Importance of Input Parameters to Annual Energy Consumption for 78% RE, 2" Insulation on Natural Gas Water Heaters

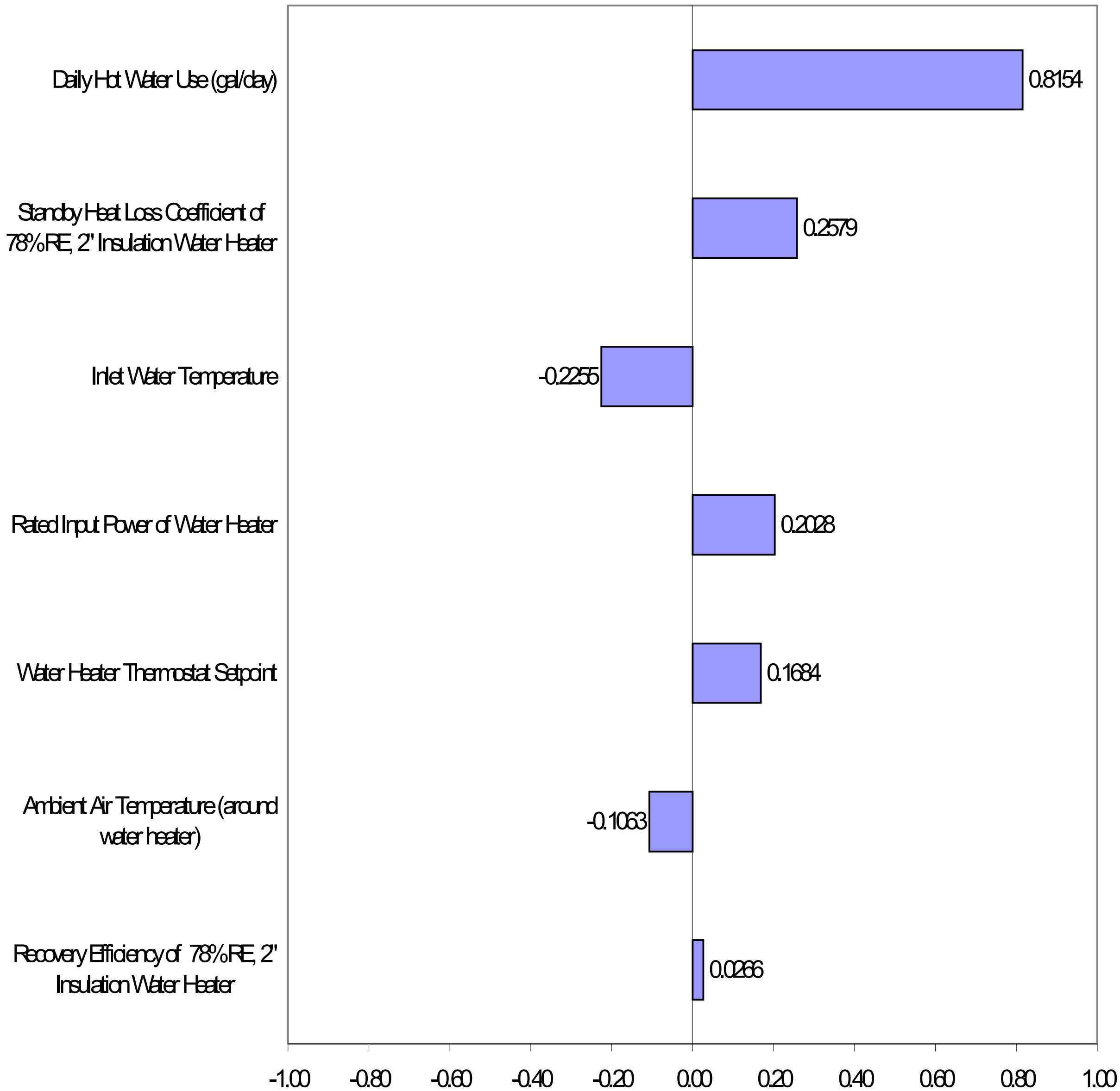

Figure 9.3.8 Importance of Input Parameters to Annual Energy Consumption for 78% RE, 2" Insulation on LPG Water Heaters

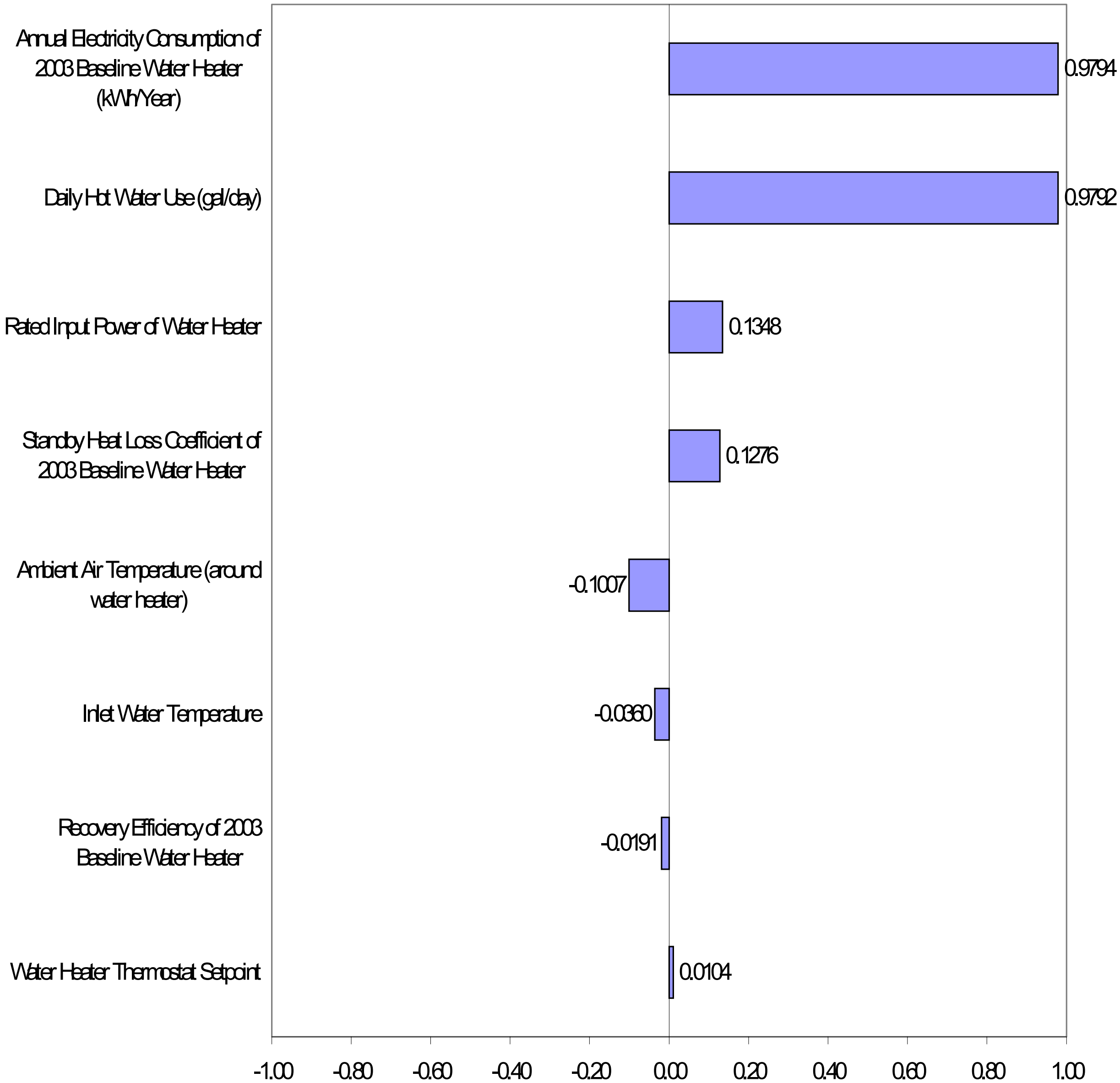

Figure 9.3.9 Importance of Input Parameters to Annual Energy Consumption for 2003 Baseline on Oil-Fired Water Heaters

9.4 OPERATING COST MODULE

9.4.1 Introduction to Operating Cost Module

Operating a water heater involves two costs: fuel to operate the water heater and maintenance to keep the water heater running properly. Fuel costs depend on the water heater's energy usage and the per-unit cost of fuel. Maintenance costs depend on water heater design.

Four types of fuel are commonly used in residential water heaters—electricity, natural gas, LPG, and fuel oil. More than one type of fuel may be used; for instance, electric water heaters use only electricity, whereas natural gas and LPG water heaters use gas or LPG plus electricity for some designs. All oil-fired water heaters use some electricity.

9.4.2 Equations for the Operating Cost Module

A generalized equation that describes the operating costs of all four types of water heaters—electric, natural gas, LPG, and oil-fired—can be expressed as follows:

$$OprCost_{year,\,option} = \sum_{EnergyType \in elec,gas,oil} \begin{pmatrix} AnnualQ_{EnergyType,\,base} \times FutrPrice_{EnergyType,\,year} \\ - AnnualQ_{EnergyType,\,option} \times FutrMarPrice_{EnergyType,\,year} \\ + MaintCost \end{pmatrix}$$

For each type of water heater, the generic formula shows different specific forms.

9.4.2.1 Electric Water Heater Operating Cost Equations

$$OprCost_{year,option} = AnnualQin_{base} \times FutrElecPrice_{year} - [AnnualQin_{base} - AnnualQin_{option}] \times FutrElecMarPrice_{year} + MaintCost$$

and

$$FutrElecPrice_{year} = ElecPrice_{98} \times ElecIncrRatio_{year}$$

and

$$ElecPrice_{98} = ElecRate \times ElecScaler$$

and

$$FutrElecMarPrice_{year} = ElecMarPrice \times ElecIncrRatio_{year}$$

where:

AnnualQin	=	average annual electricity consumption (kWh/year)
FutrElecPrice	=	future price of electricity expressed in 1998$ (¢/kWh)
$ElecPrice_{98}$	=	revised RECS house average electricity price expressed in 1998$ (¢/kWh)
ElecIncrRatio	=	ratio of future electricity price to 1998 price
ElecRate	=	RECS house average electricity price, derived from RECS billing data, expressed in 1997$ (¢/kWh)
ElecScaler	=	a conversion factor for electricity price change that is the ratio of the average electricity price in 1998 to that in 1997.
FutrElecMarPrice	=	future marginal price of electricity expressed in 1998$ (¢/kWh)
ElecMarPrice	=	RECS house marginal electricity price from regression analysis of RECS billing data
MaintCost	=	No maintenance cost incurred for electric water heaters

9.4.2.2 Natural Gas and LPG Water Heater Operating Cost Equations

$$\begin{aligned} OprCost_{year,option} = {} & (AnnualQelec_{base} \times FutrElecPrice_{year}) + (AnnualQgas_{base} \times FutrFuelPrice_{year}) - \\ & [(AnnualQelec_{base} - AnnualQelec_{option}) \times FutrElecMarPrice_{year}] - \\ & [(AnnualQgas_{base} - AnnualQgas_{option}) \times FutrFuelMarPrice_{year}] + MaintCost \end{aligned}$$

and

$$FutrFuelPrice_{EnergyType,year} = FuelPrice_{EnergyType,\,98} \times FuelIncrRatio_{EnergyType,year}$$

$$FutrFuelMarPrice_{EnergyType,year} = FuelMarPrice_{EnergyType} \times FuelIncrRatio_{EnergyType,year}$$

and, if EnergyType = Natural Gas, then

$FuelPrice_{98} = FuelRate \times GasScaler$

or, if EnergyType = LPG, then

$FuelPrice_{98} = FuelRate \times LPGScaler$

where:

AnnualQelec	=	annual electricity consumption (kWh/year)
AnnualQgas	=	annual water heating fuel consumption (MMBtu/year)
FutrFuelPrice	=	future price of water heating fuel($/MMBtu)
$FuelPrice_{98}$	=	revised water heating fuel price in 1998$ ($/MMBtu)
FuelIncrRatio	=	ratio of future water heating fuel price to 1998 price
FuelRate	=	RECS house water heating fuel price in 1997$ ($/MMBtu)
GasScaler	=	a conversion factor for natural gas price change that is the ratio of the average natural gas price in 1998 to that in 1997.
LPGScaler	=	a conversion factor for LPG price change that is the ratio of the average LPG price in 1998 to that in 1997.
FutrFuelMarPrice	=	future marginal price of water heating fuel in 1998$
FuelMarPrice	=	RECS house marginal water heating fuel price[a]
MaintCost	=	Annual maintenance cost that only occurs for Side-Arm gas water heaters when a pump replacement is needed.

[a] For LPG, the marginal price is assumed to be the same as the average price.

9.4.2.3 Oil-Fired Water Heater Operating Cost Equations

$$OprCost_{year,option} = (AnnualQelec_{base} \times FutrElecPrice_{year}) + (AnnualQoil_{base} \times FutrOilPrice_{year}) - [(AnnualQelec_{base} - AnnualQelec_{option}) \times FutrElecMarPrice_{\mathrm{year}}] - [(AnnualQoil_{base} - AnnualQoil_{option})] \times FutrOilPrice_{year} + MaintCost_{option}$$

and

$$FutrOilPrice_{year} = OilPrice_{98} \times OilIncrRatio_{year}$$

$$OilPrice_{98} = OilRate \times OilScaler$$

where:

AnnualQoil	=	annual fuel oil consumption (MMBtu/year)
FutrOilPrice	=	future price of fuel oil ($/MMBtu)
Inflator97	=	an inflation factor to convert 1997$ in AEO99[20] to 1998$
Inflator96	=	an inflation factor to convert 1996$ in GRI98[21] to 1998$
$OilPrice_{98}$	=	revised fuel oil price in 1998$ ($/MMBtu)
OilIncrRatio	=	ratio of future fuel oil price to 1998 price
OilRate	=	RECS house fuel oil price in 1993$ ($/MMBtu)
OilScaler	=	a conversion factor for fuel oil price change that is the ratio of the average oil price in 1998 to that in 1993.
MaintCost	=	Annual maintenance cost of oil water heaters

9.4.3 General Description of Key Variables

AnnualQin is the average annual energy consumption, i.e., the total amount of energy consumed by the water heater to heat water and to keep it hot. For electric water heaters, AnnualQin is in kWh/yr. For fuel-fired water heaters, this is in Btu/yr.

AnnualQelec is the annual electricity consumption for oil-fired water heaters and for the electronic ignition system and pump for side arm designs in gas-fired water heaters (kWh/yr).

AnnualQgas is the annual natural gas or LPG consumption of the water heater (MMBtu/year).

AnnualQoil is the annual fuel oil consumption of the water heater (MMBtu/year).

FutrElecPrice is the price of electricity (¢/kWh) in each future year. It is calculated as a product of **$\mathbf{ElecPrice_{98}}$** and **ElecIncrRatio**.

FutrFuelPrice is the price of water heating fuel ($/MMBtu) in each future year. It is calculated as a product of **$\mathbf{FuelPrice_{98}}$** and **FuelIncrRatio** for a particular fuel type.

FutrOilPrice is the price of fuel oil ($/MMBtu) in each future year. It is calculated as a product of **$\mathbf{OilPrice_{98}}$** and **OilIncrRatio**.

$\mathbf{ElecPrice_{98}}$ is the revised electricity price (¢/kWh) in 1998. It takes the RECS household electricity price (**ElecRate**) and multiplies it by **ElecScaler** to change 1997$ to 1998$ to account for inflation and electricity price change.

$\mathbf{FuelPrice_{98}}$ is the revised natural gas or LPG price ($/MMBtu) in 1998. It takes the RECS household energy price (**FuelRate**) and multiplies it by the corresponding scalar for gas or LPG, respectively, to change 1997$ to 1998$ to account for inflation and fuel price change.

$\mathbf{OilPrice_{98}}$ is the revised fuel oil price ($/MMBtu) in 1998. It takes the RECS household oil price (**OilRate**) and multiplies it by **OilScaler** to change 1993$ to 1998$ to account for inflation and fuel oil price change.

ElecIncrRatio is the ratio of national average electricity price between each future year and 1998 for the selected scenario. 1998 is the base year.

FuelIncrRatio is the ratio of national average natural gas or LPG price between each future year and 1998 for the selected scenario. 1998 is the base year.

OilIncrRatio is the ratio of national average oil price between each future year and 1998 for the selected scenario. 1998 is the base year.

ElecRate is the price of electricity for the household as calculated from RECS billing data (in 1997$). The electricity price is defined as the average price per unit electricity (kWh) consumed.

FuelRate is the price for the household of LPG or of natural gas as calculated from RECS billing data (in 1997$). The fuel price is defined as the average price per unit fuel (MMBtu) consumed.

OilRate is the price of fuel oil for the household as calculated from RECS billing data (in 1993$). The oil price is defined as the average price per unit oil (MMBtu) consumed.

ElecScaler is a conversion factor for electricity price change, represented by the ratio of electricity prices in 1998 to electricity prices in 1997, in nominal dollars.[a]

$$= \frac{\textit{National Average Price}_{1998}}{\textit{National Average Price}_{1997}} = 0.9798$$

GasScaler is a conversion factor for gas price change in nominal dollars.

$$= \frac{\textit{National Average Price}_{1998}}{\textit{National Average Price}_{1997}} = 0.9827$$

LPGScaler is a conversion factor for LPG price change in nominal dollars.

$$= \frac{\textit{National Average Price}_{1998}}{\textit{National Average Price}_{1997}} = 0.7337$$

OilScaler is a conversion factor for oil price change in nominal dollars.

$$= \frac{\textit{National Average Price}_{1998}}{\textit{National Average Price}_{1993}} = 0.7990$$

ElecMarPrice is the marginal price of electricity for each RECS household expressed in 1998$ (¢/kWh).

FuelMarPrice is the marginal price of water heating fuel (natural gas, LPG, and oil) for each RECS household in 1998$ ($/MMBtu).

FutrElecMarPrice is the future marginal price of electricity for each RECS household expressed in 1998$ (¢/kWh).

FutrFuelMarPrice is the future marginal price of water heating fuel (natural gas, LPG, and oil) for each RECS household in 1998$ ($/MMBtu).

MaintCost is the price of regular maintenance or the price to repair a water heater when it fails ($/year). In reality, if electric or gas-fired (both natural gas and LPG) water heaters fail, residential

[a] The oil-fired analysis was not updated from 1993 RECS to 1997 RECS because only a small number of households have oil-fired water heaters. So, the ElecScaler for the oil analysis is the ratio of the 1998 to 1993 prices, or 0.9940.

consumers tend to replace the heaters rather than having them serviced. Therefore, the maintenance cost for electric and baseline gas-fired water heaters are assumed to be zero. Oil-fired water heaters and burners are cleaned and maintained regularly; therefore, we account for maintenance costs for these heaters. The maintenance cost associated with all sizes of baseline oil-fired models is $97.14 per year. This mean value comes from a collection of annual maintenance contract prices, which were gathered from telephone conversations with seven oil-fired equipment suppliers in the eastern U.S. [22] Note that the costs are from separate maintenance contracts only for water heaters. Costs may go down significantly if multiple oil-fired appliances in a household are on the same contract.

9.4.4 Energy Prices

9.4.4.1 Introduction

We calculate energy prices as the per-unit cost of fuel for the four types of fuel (electricity, natural gas, LPG, and oil) from the ratios of fuel expenditures to consumption, as reported in billing data for the RECS97 household in 1997$ (RECS93 and 1993$ for oil-fired households). We then converted the energy prices into 1998$ using scalars—ratios of average nominal fuel prices in 1998 to 1997 (or 1993 in the case of oil-fired)—to take into account both energy price changes and inflation during the time period.

The converted RECS sample energy prices (called "revised energy prices" in the spreadsheets) serve as the base year prices for the future energy price series of four energy price scenarios (which were *AEO2000* Reference, *AEO2000* Low Growth, *AEO2000* High Growth, and *GRI2000,* for gas-fired or electric, and *AEO99* Reference, *AEO99* Low Growth, *AEO99* High Growth, and *GRI98* for oil-fired, see section immediately following for details).

We use the future energy price series of the scenarios to compute price ratios between future years and 1998. These are then used to estimate future energy prices of RECS household samples by multiplying the ratio by the revised RECS energy prices. All calculations are in 1998$.

We calculate future marginal energy prices using the same ratios and the derived marginal energy prices from RECS household samples. The details of the derivation of the RECS marginal rate are given below in Section 9.4.4.3.

9.4.4.2 Future Energy Prices

Future fuel costs will vary from house to house. Two primary factors contribute to this variation. One is the existing variability in energy prices, which depends on the rate schedule of the local utility and the consumption pattern of the particular household. The other is the uncertainty of future energy prices,[23] which is further complicated by the current restructuring of the electric supply industry.

To deal with variations in energy prices, we derived marginal energy prices for RECS households in order to establish energy price variability from house to house. To account for future uncertainties, we applied various scenarios of projected future energy prices (trends by national average) to each household's marginal energy price. The following four possible fuel price scenarios were built into the LCC calculations:[a]

Annual Energy Outlook 2000, High Economic Growth[7]
Annual Energy Outlook 2000, Reference Case
Annual Energy Outlook 2000, Low Economic Growth
2000 Edition of the GRI Baseline Projection [24]

Figures 9.4.1 through 9.4.4 show the trends for the projected future prices for each of the four water heater fuels (electricity, gas, LPG, and oil).

The figures show that all electricity price projections are declining; the price projections for gas and LPG are more varied. Oil prices remain relatively flat in the *GRI98* scenario, and rise in the *AEO* scenarios.

After we adjusted for inflation and energy price changes, we scaled energy prices for the RECS households from the starting year by the projected average future energy prices. Thus, each sample house from RECS has four different future annual energy price series associated with it. We estimated future annual operating costs as annual energy use multiplied by the annual energy price series for each of the four scenarios. Section 9.4.5 gives a detailed description of how the calculation is implemented in the spreadsheet models.

[a] The oil-fired analysis was not updated because only a small number of households use oil-fired water heaters. Therefore, for this analysis, the projections used were from *AEO99* Reference Case, High and Low Growth Cases, and *GRI98.*

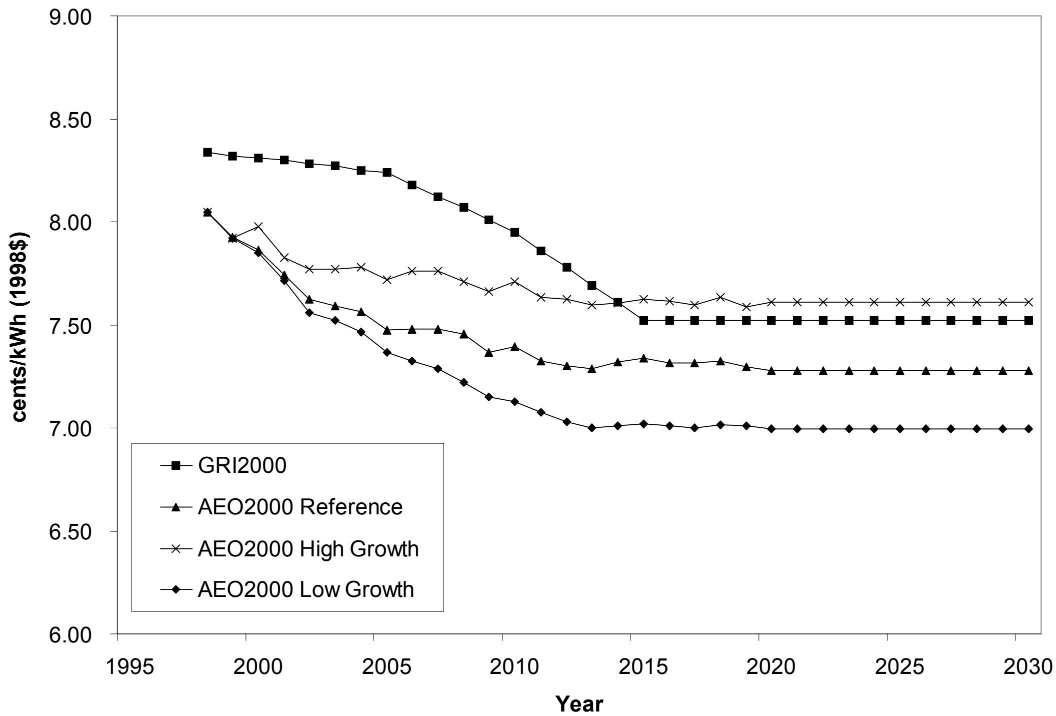

Figure 9.4.1 Electricity Price Scenarios

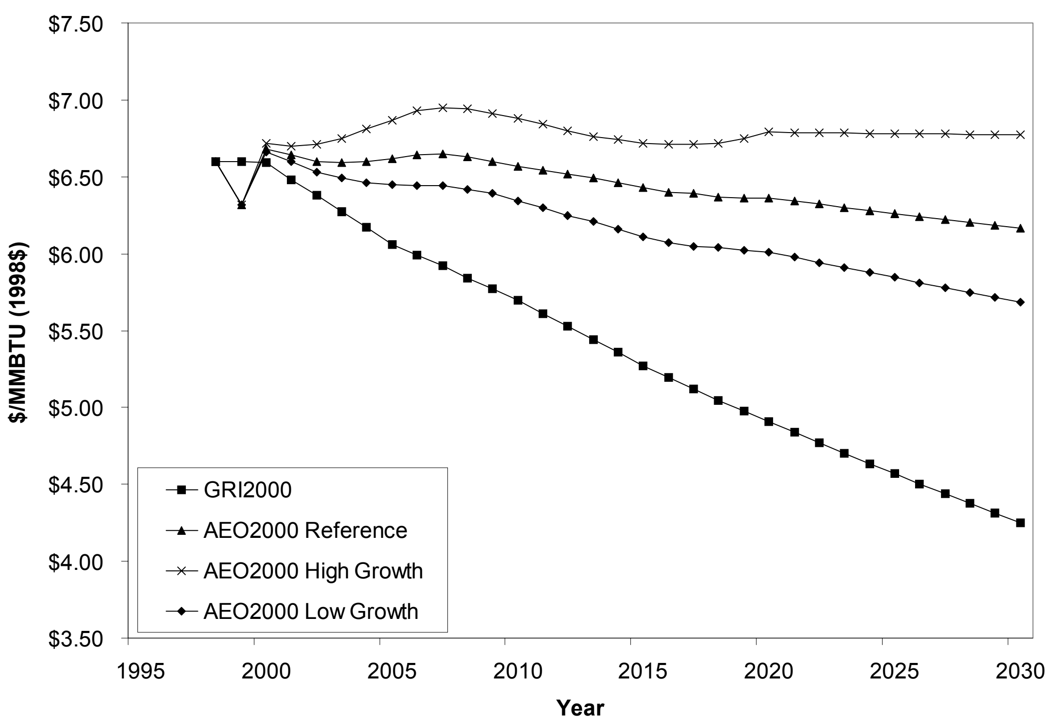

Figure 9.4.2 Natural Gas Price Scenarios

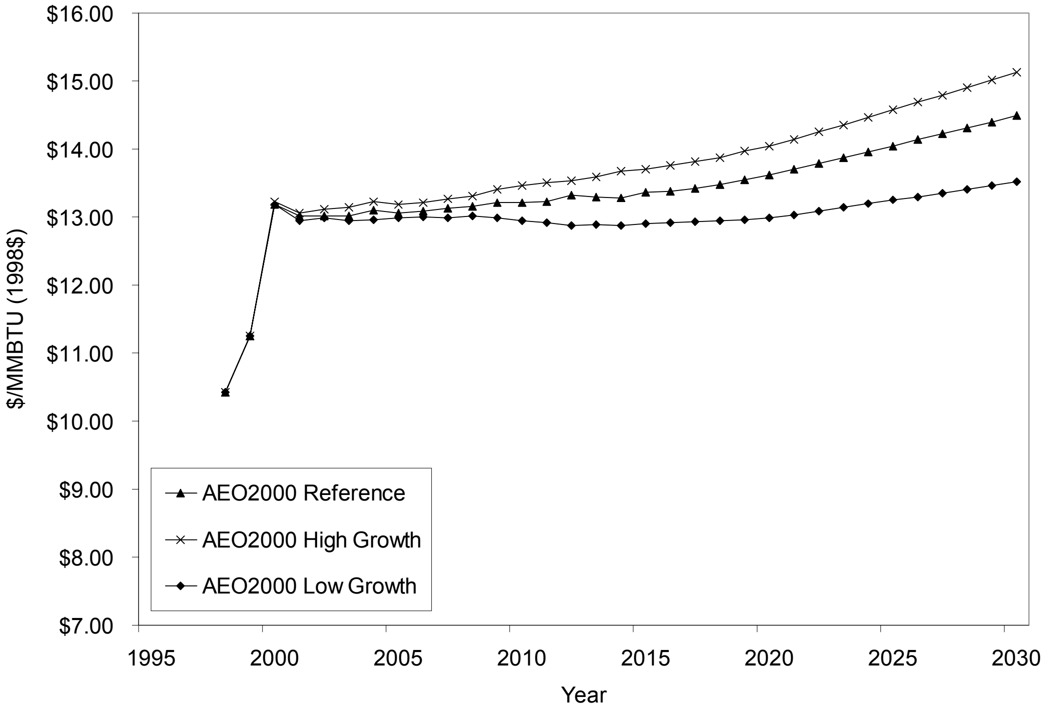

Figure 9.4.3 LPG Price Scenarios

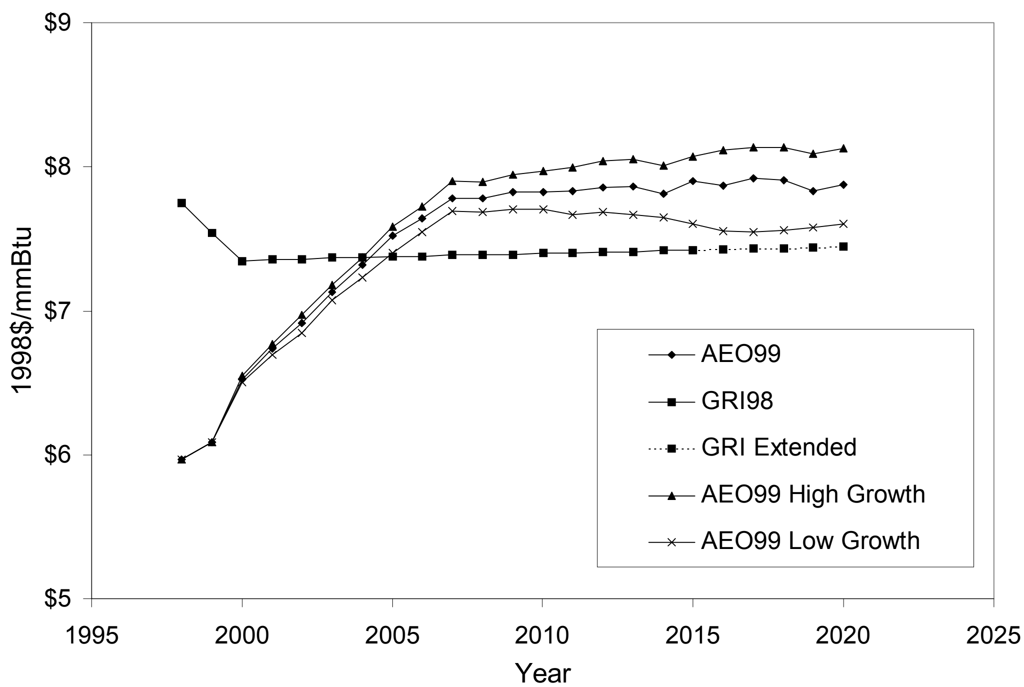

Figure 9.4.4 Oil Price Scenarios

9.4.4.3 Marginal Energy Prices

Overview. Previous analyses of the life-cycle costs of and consumer bill savings possible from appliance energy efficiency standards were based on *average* energy prices.[a] Using *marginal* energy prices in these analyses is more theoretically sound.[b] Accordingly, in April 1998 the Advisory Committee on Appliance Energy Efficiency Standards delivered a letter to the Secretary of Energy recommending, among other things, that DOE replace the use of national average energy prices with the full range of consumer marginal energy prices in its life-cycle cost analyses. Because neither published nor readily available data existed for consumer marginal energy prices, a major research effort was required to derive consumer marginal energy prices.

Method. We estimated seasonal marginal electricity and natural gas for RECS households as the slope of the regression line between household monthly bill and corresponding consumption.[c] For oil and LPG, average fuel price for each household was used, because the marginal fuel price is not expected to be significantly different from the average, as discussed below.

For electricity, we divided the billing data into two seasons, summer and "non-summer", where a bill was defined to be a summer bill if the midpoint of the billing period fell between June 1 and September 30 and "non-summer" was the remainder of the year. This division was done because electric utilities often have different rates in summer vs. non-summer, and most utilities define summer to fall within this range of dates. We used these seasonal marginal prices by household directly in the LCC analysis. For RECS97, natural gas billing data was split into seasons in a manner parallel to electricity data. The "peak" winter season was defined as those billing periods whose midpoint fell in any of the following four months: November, December, January, February. The remaining eight months constitute the non-winter season. In addition to the two seasonal regressions for each household, a single "annual" regression using all of the data for the household was also performed.

The criterion for accepting regression line slopes as marginal prices was established using an r^2 cutoff of 0.90. That is, regression slopes of household billing data were not accepted as household marginal prices unless the r^2 value was at least 0.90. This criterion was used with both the electricity and natural gas billing data.

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[a] *Average* energy prices for a consumer are derived by dividing annual energy costs by annual energy consumption. At the utility level, average energy prices are derived by dividing annual revenues by annual energy sales.

[b] *Marginal* prices as discussed here are those prices consumers pay (or save) for their last units of energy used (or saved). Marginal prices reflect a change in a consumer's bill (that might be associated with new energy efficiency standards) divided by the corresponding change in the amount of energy the consumer used.

[c] We thank Robert Latta, U.S. DOE, Energy Information Administration, for first proposing this approach.

We calculated the annual equivalent marginal energy price by weighting the summer and non-summer marginal energy prices by the fraction of annual water heater energy consumption that occurs in those seasons. Monthly allocation factors—the fraction of annual energy consumption in a given month—were determined as the weighted averages of the results of six different water heater energy use field studies.[26, 27, 28, 29, 30, 31] These studies collectively metered 527 households, nationwide, from 1978 to 1994. The marginal electric price for summer months was weighted at 28.9%, the non-summer months at 71.1%. The marginal natural gas price for the winter months was weighted at 36.9%, the non-winter months at 63.1%. For households where one or both seasonal regressions did not yield acceptable results (not enough points to calculate, or r^2 too low) but the "annual" regression did, the annual value was used as that household's marginal price.

For both electricity and natural gas, we performed a statistical analysis comparing the data sets for each fuel before and after dropping the households for which we were unable to calculate marginal energy prices, in order to determine if any bias was being introduced by dropping those households. We found that the households that were dropped were disproportionately those whose utility bills were included in the household's rent; billing data could not be collected from those households. Other than this, no major differences were found between the data sets.

We also examined prices of residential fuel oil and LPG. We conducted brief telephone interviews of fuel oil and LPG distributors from January 25 to February 5, 1999 in order to understand and characterize regional variations in pricing and distribution of fuel oil and LPG. We selected a sample of distributors from relevant Internet sites, including that of the National Propane Gas Association. The goal was to interview distributors that represent a cross-section of the industry in terms of company size and location. Questions were designed to identify factors (including wholesale price, annual usage, delivery, tank rental, and taxes) that affect the actual cost of fuel oil and LPG for residential customers and to determine any divergence between average and marginal price for these fuels.

Because our interviews indicated that bills paid by residential consumers for both fuel oil and LPG are essentially volume-driven, with a single block rate, we calculated the average prices inherent in those bills, as reported in RECS, as being equivalent to marginal prices for the purposes of the LCC price analysis.

Average prices for all four fuels were calculated for each RECS household using the available billing data for that household. These average prices were then used to calculate the percent difference between marginal price and average price for that household. Weighted means of the percent difference between marginal price and average price were also calculated for the set of households with acceptable seasonal prices, the set of households without acceptable seasonal prices, and for all of the households.

Results of the Analysis. Table 9.4.1 below display the results of the residential electricity price analysis by showing the relationship between marginal electricity prices and average electricity prices for the residential sector in the summer and the non-summer. Table 9.4.2 displays the results of the residential natural gas price analysis.

Table 9.4.1 Marginal Residential Electricity Prices - RECS97

Electricity – RECS97		Prices (¢/kWh, in 1997$) (Weighted Mean)		% Difference between Marginal Price and Average Price	
		Marginal	Annual Average	Weighted Mean	Range
Households w/Acceptable Seasonal Prices	Summer	9.1	9.4	-2.5%	-76.1% to +288.9%
	Non-Summer	8.5		-10.0%	-72.2% to +73.3%
Households w/o Acceptable Seasonal Prices		9.0	9.6	-4.5%	-55.3% to +397.5%
All Households		8.7	9.4	-6.9%	

Table 9.4.2 Marginal Residential Natural Gas Prices - RECS97

Natural Gas – RECS97		Prices (¢/ccf, in 1997$) (Weighted Mean)		% Difference between Marginal Price and Average Price	
		Marginal	Annual Average	Weighted Mean	Range
Households w/Acceptable Seasonal Prices	Winter	70.1	76.5	-4.4%	-96.5% to +179.4%
	Non-Winter	63.7		-15.3%	-81.6% to +57.9%
Households w/o Acceptable Seasonal Prices		66.4	82.4	-14.5%	-90.8% to +33.7%
All Households		66.0	78.5	-12.6%	

In this analysis, we used the marginal electricity and natural gas prices that we derived directly from RECS. For Tables 9.4.1 and 9.4.2, any household showing a negative percent difference between marginal price and average price indicates that the household's marginal price is smaller than the household's average price. A positive percent difference between marginal price and average price indicates that the household's marginal price is larger than the household's average price. Those marginal electricity prices in the summer (June-September) range from 76% below to 289% above the average price for the same customer. At the consumption-weighted mean of the differences, marginal electricity prices are 2.5% lower than average electricity prices in the summer. Marginal natural gas prices range from 96% below to 179% above the average price for the same customer. At the consumption-weighted mean of the differences, marginal natural gas prices are 4.4% lower than average natural gas prices.

9.4.5 General Description of Data Sources and Calculations in Spreadsheets

We calculate average annual energy consumption input to the operating cost module with WHAM (see Section 9.3.1 for a full discussion of WHAM). In the electric water heater model, average annual energy consumption represents the annual electricity use of a water heater (**AnnualQin**). For water heaters that use more than one type of fuel, we calculate the annual usage of each type of fuel separately. For instance, in some designs of gas-fired water heaters, **AnnualQin** is a sum of the annual natural gas or LPG (**AnnualQgas**) and the electricity consumption (**AnnualQelec**).

We use fuel rates as reported for 1997 RECS[a] as a base to capture the variability of fuel prices across the nation. We use Gross Domestic Product (GDP) indices from the U.S. Department of Commerce, Bureau of Economic Analysis, to calculate **Inflator96** and **Inflator97** (used in the oil analysis only), which are 1.0290 and 1.0102, respectively.

Similarly, we use national average energy prices reported in the EIA *Annual Energy Review* [32] to compute scalars (**ElecScaler**, **GasScaler**, **LPGScaler,** and **OilScaler**) so that they take into account energy price changes since the 1997 RECS survey (or 1993, in the case of oil). Multiplying **FuelRate** by the corresponding scalar yields the value of unit fuel price (**Elec/Fuel/OilPrice**) in 1998$ for each RECS household.

DOE/EIA publishes projections of future energy prices in its *Annual Energy Outlook 2000* (*AEO2000*).[7] The projections include three cases: reference, high economic growth, and low economic growth. These three projections show a similar pattern but vary in magnitude. The Gas Research Institute (GRI) also publishes a forecast for future fuel rates (electricity, natural gas, and oil) in its *2000 Edition of the GRI Baseline Projection*.[24] (See Figures 9.4.1, 9.4.2, and 9.4.4.) We use the four scenarios to help demonstrate how future energy price trends affect the outcome of the LCC analysis[b]. Since our analysis covers the period through 2030, and the projections only go through 2020 for *AEO* and 2015 for *GRI*, we extended the projections to 2030 as follows. For electricity, we project that prices will remain flat, assuming that the current restructuring of this market will have reached equilibrium. For natural gas, LPG, and oil, we take the annual rate of growth in prices from 1998 through the end of the projection period, and assume this same growth through 2030.

Two additional details regarding the GRI forecast scenario need to be noted. First, the GRI forecast only predicts prices for the years 1998, 2000, 2005, 2010, and 2015. We did a linear

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[a] 1993 RECS for oil. The oil-fired analysis was not updated with 1997 RECS values because only a small number of water heaters are oil-fired.

[b] Because the oil analysis was not updated, *AEO99* and *GRI98* price scenarios were used. Because *GRI98* fuel price projections are reported as 1996$, we convert them into 1998$ (multiplied by **Inflator96**). Similarly, we convert *AEO99* fuel price projections, reported in 1997$, into 1998$ (multiplied by **Inflator97**).

interpolation of prices for the other years between 1998 and 2015. Second, GRI does not include a projection for future LPG prices. We therefore only analyzed the three *AEO* scenarios for LPG water heaters

We derive the incremental ratios of the energy price scenarios (**ElecIncrRatio** for electricity, **FuelIncrRatio** for gas and LPG, and **OilIncrRatio** for fuel oil) by dividing each year's projected price by the 1998 price. We apply the result to the corresponding **Elec/Fuel/OilPrice** of each RECS sample house to represent its future energy prices (**FutrElecPrice** for electricity, **FutrFuelPrice** for gas and LPG, **FutrOilPrice** for fuel oil) for the selected scenario. We then compute the annual operating costs of the water heater based on the equations described in Section 9.4.2.

The derivation of marginal prices is discussed in Section 9.4.4.2, above.

9.4.6 Operating Cost Results

9.4.6.1 Electric Water Heater Operating Costs

Table 9.4.3 lists the average annual operating costs for the 2003 baseline and design options for all sizes of electric water heaters, based on 1997 RECS. The average operating cost savings from the baseline are listed for each design option.

Table 9.4.3 Operating Costs for Electric Water Heaters

Design Option		Average Annual Operating Cost *($)*	Average Savings from Baseline *($)*
0	2003 Baseline	256	–
1	Heat Traps	252	4.00
2	Tank Bottom Insulation	251	5.39
3	2" Insulation	246	9.80
4	2.5" Insulation	243	13.05
5	Plastic Tank	242	13.64
6	3" Insulation	240	15.66

Figure 9.4.5 shows a distribution and cumulative frequency plot of the difference in operating cost for each design option compared to the 2003 baseline for electric water heaters. Note that a negative difference in operating cost for a given design option indicates a savings. The width of the plot shows the spread of savings in the population. In general, the design options with higher efficiencies tend to show a wider spread of energy savings in the population.

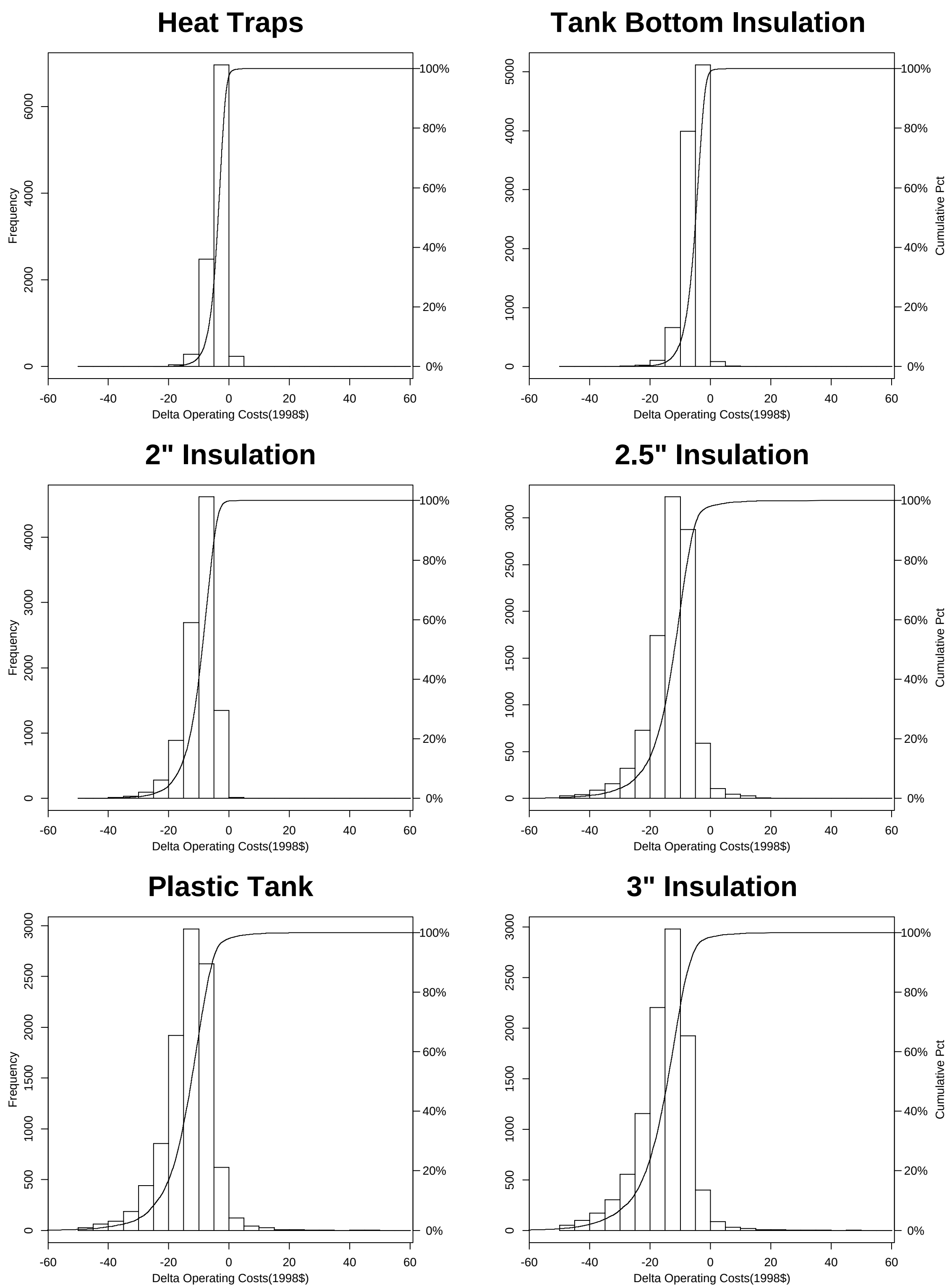

Figure 9.4.5 Difference in Operating Costs by Design Option for Electric Water Heaters

9.4.6.2 Natural Gas Water Heater Operating Costs

Table 9.4.4 lists the average annual operating costs for the 2003 baseline and for design options for all standard sizes of natural gas water heaters, based on 1997 RECS data. The average operating cost savings compared to the 2003 baseline are listed for each design option.

Table 9.4.4 Operating Costs for Natural Gas Water Heaters

Design Option		Average Annual Operating Cost *($)*	Average Savings from Baseline *($)*
0	2003 Baseline	160	–
1	Heat Traps	158	2.81
2	78% RE	155	5.21
3	78% RE, 2" Insulation	148	12.74
4	78% RE, 2.5" Insulation	146	14.19
5	80% RE, 2" Insulation	145	15.76
6	80% RE, 2.5" Insulation	143	17.24
7	80% RE, 3" Insulation	142	18.18
8	Side Arm	126	33.95

Figure 9.4.6 shows a distribution and cumulative frequency plot of the difference in operating cost for each design option compared to the 2003 baseline for natural gas water heaters. Note that a negative difference in operating cost for a given design option indicates a savings. The width of the plot shows the spread of savings in the population. In general, the design options with higher efficiencies tend to show a wider spread.

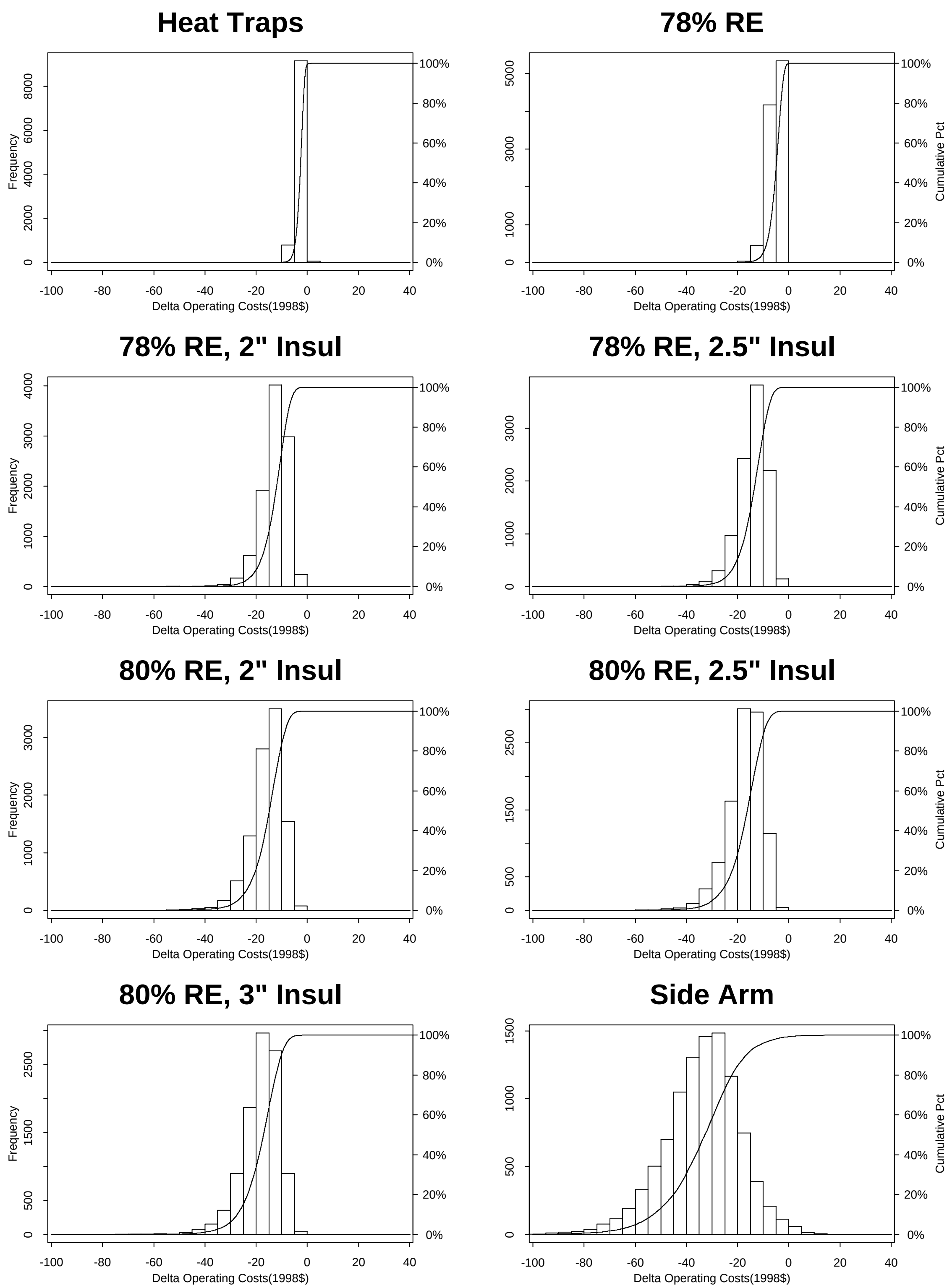

Figure 9.4.6 Difference in Operating Costs by Design Option for Natural Gas Water Heaters

9.4.6.3 LPG Water Heater Operating Costs

Table 9.4.5 lists the average annual operating costs for the 2003 baseline and for design options for all standard sizes of LPG water heaters, based on 1997 RECS data. The average operating cost savings compared to the 2003 baseline are listed for each design option.

Table 9.4.5 Operating Costs for LPG Water Heaters

Design Option		Average Annual Operating Cost ($)	Average Savings from Baseline ($)
1	2003 Baseline	257	–
2	Heat Traps	251	5.59
3	78% RE	247	9.92
4	78% RE, 2" Insulation	232	24.59
5	78% RE, 2.5" Insulation	229	27.52
6	80% RE, 2" Insulation	226	30.48
7	80% RE, 2.5" Insulation	223	33.38
8	80% RE, 3" Insulation	222	35.12
9	Side Arm	186	70.54

Figure 9.4.7 shows a distribution and cumulative frequency plot of the difference in operating cost for each design option compared to the 2003 baseline for LPG water heaters. Note that a negative difference in operating cost for a given design option indicates a savings. The width of the plot shows the spread of savings in the population. In general, the design options with higher efficiencies tend to show a wider spread.

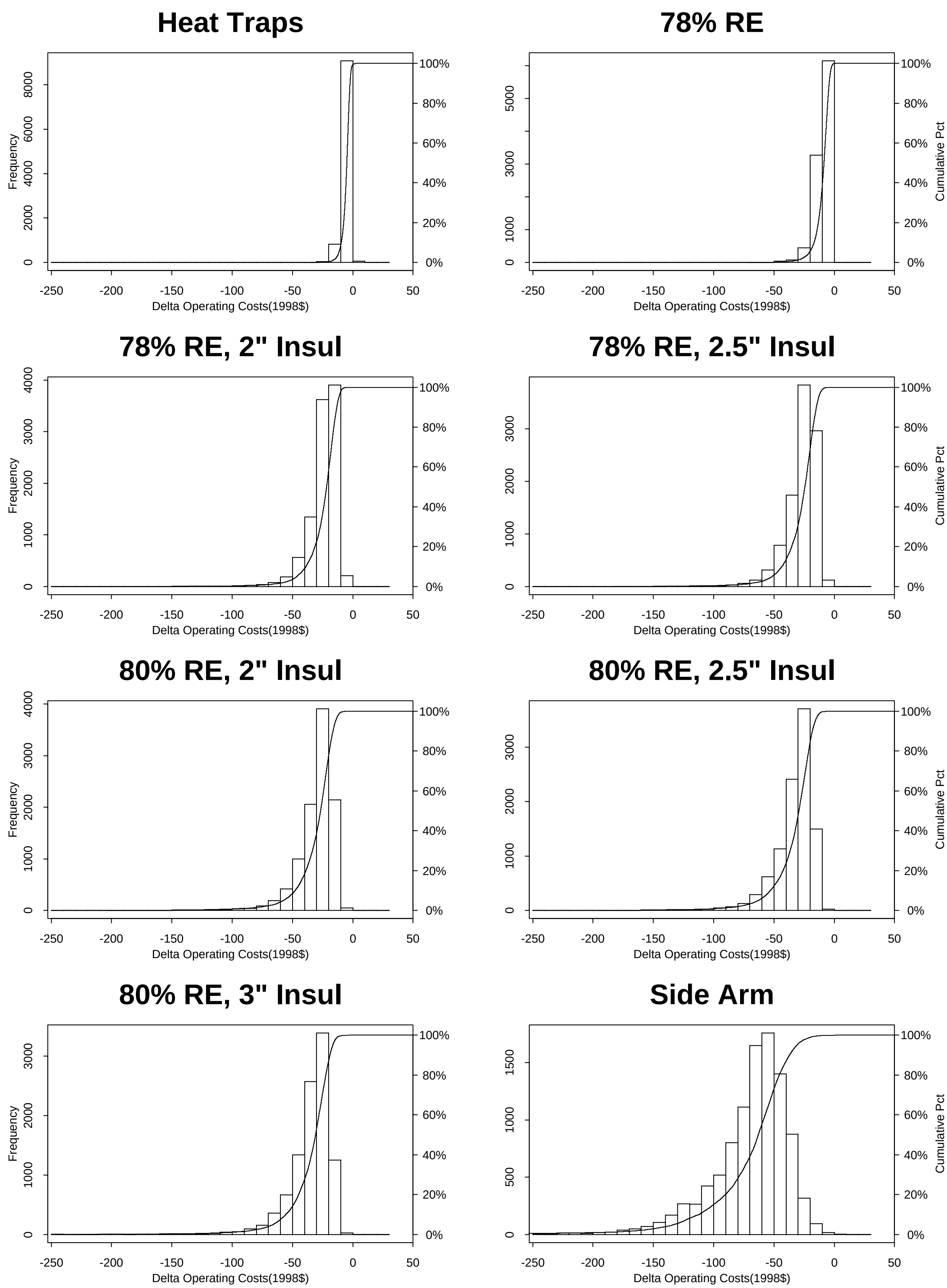

Figure 9.4.7 Difference in Operating Costs by Design Option for LPG Water Heaters

9.4.6.4 Oil-Fired Water Heater Operating Costs

Table 9.4.6 lists the average annual operating cost for the 2003 baseline and design options for standard oil-fired water heaters, based on 1993 RECS data. The average operating cost savings compared to the 2003 baseline are listed for each design option.

Table 9.4.6 Operating Costs for Oil-Fired Water Heaters

Design Option		Average Annual Operating Cost *($)*	Average Savings from Baseline *($)*
1	2003 Baseline	249	–
2	Heat Traps	247	2.22
3	2" Insulation	241	8.12
4	2.5" Insulation	240	9.47
5	3" Insulation	239	10.37
6	78% RE	233	16.14
7	Interrupted Ignition	229	20.25
8	Increased HX Area	222	27.35

Figure 9.4.8 shows a distribution and cumulative frequency plot of the difference in operating cost for each design option compared to the 2003 baseline for oil-fired water heaters. Note that a negative difference in operating cost for a given design option indicates a savings. The width of the plot shows the spread of savings in the population. In general, the design options with higher efficiencies tend to show a wider spread.

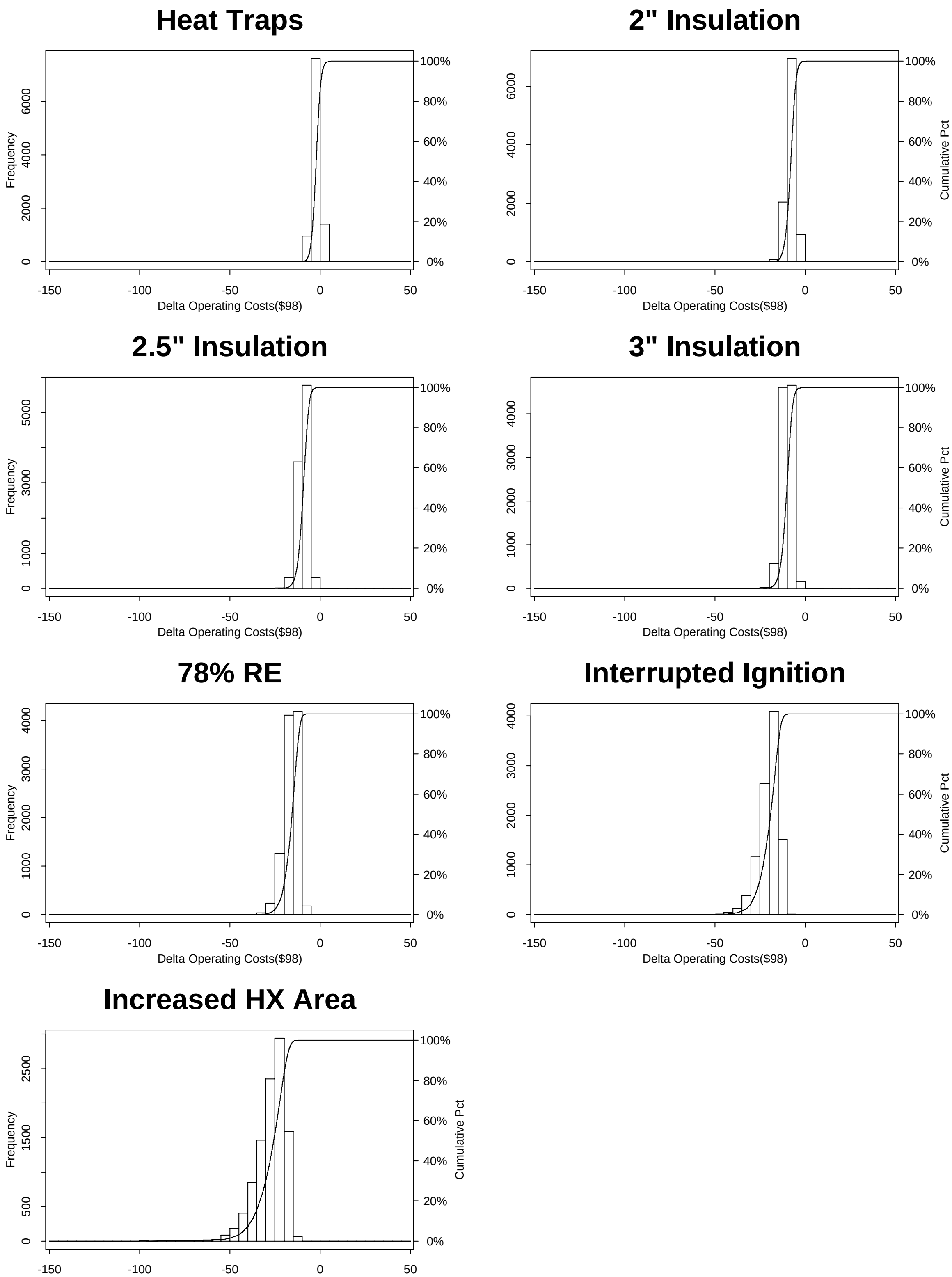

Figure 9.4.8 Difference in Operating Costs by Design Option for Oil-Fired Water Heaters

9.4.7 Importance Analysis

The following four importance charts (Figures 9.4.9 through 9.4.12) show the results of the importance analysis for operating costs at Trial Standard Level 3 for electric, natural gas, LPG, and oil-fired water heaters. Figure 9.4.9 shows the rank order correlation of input variables with the operating cost for the 2.5" Insulation design option on electric water heaters. Figures 9.4.10 and 9.4.11 show the same for 78% RE and 2.5" Insulation on natural gas and LPG water heaters, respectively. Figure 9.4.12 shows the rank order correlation for the 2003 Baseline on oil-fired water heaters. Variables are ordered with maximum correlation coefficients, positive or negative, on top and minimum coefficients on the bottom. As expected, the operating cost correlates most strongly with energy consumption for all four types of water heaters.

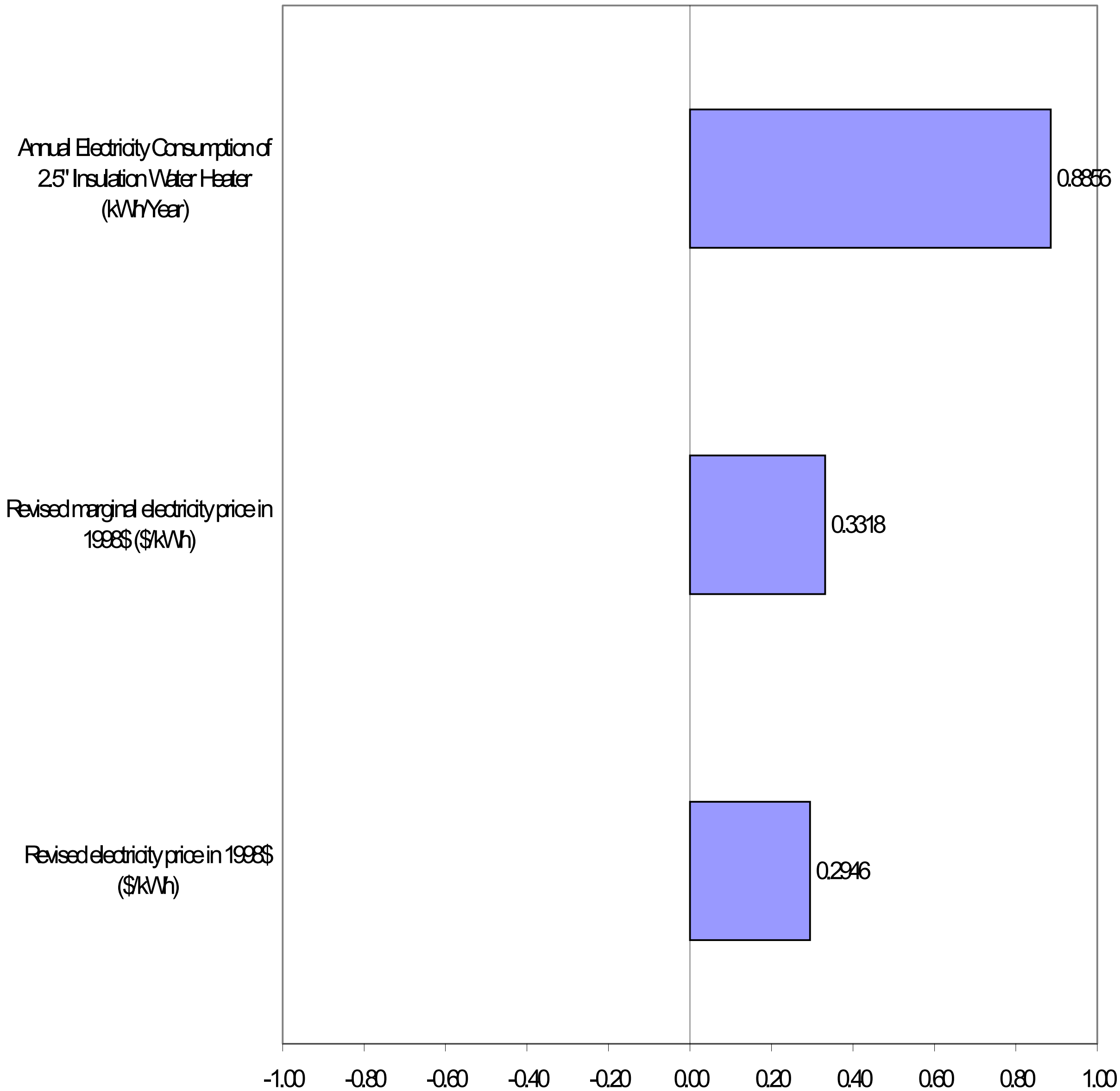

Figure 9.4.9 Importance of Input Parameters to Operating Cost for 2.5" Insulation on Electric Water Heaters

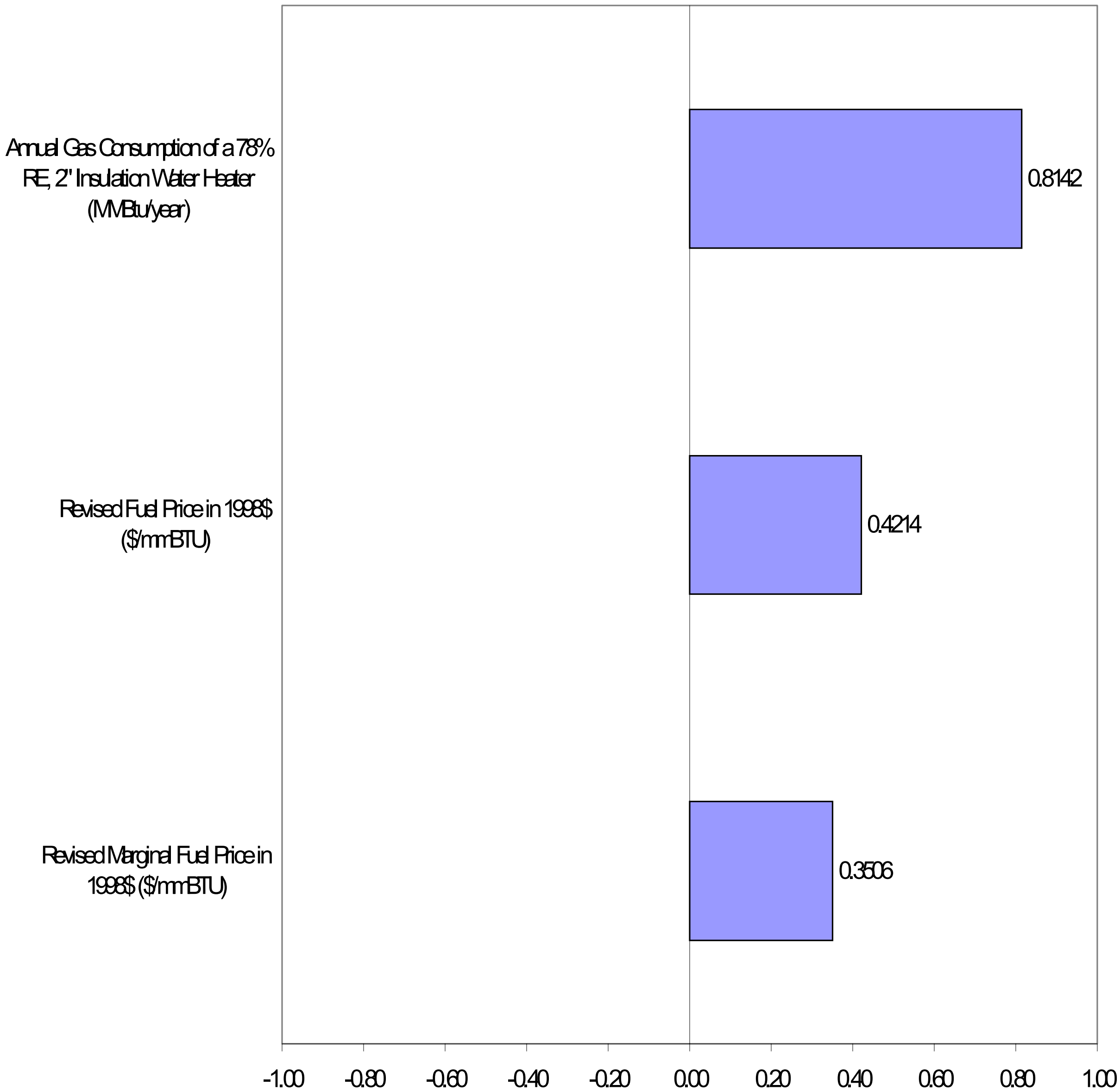

Figure 9.4.10 Importance of Input Parameters to Operating Cost for 78% RE 2" Insulation on Natural Gas Water Heaters

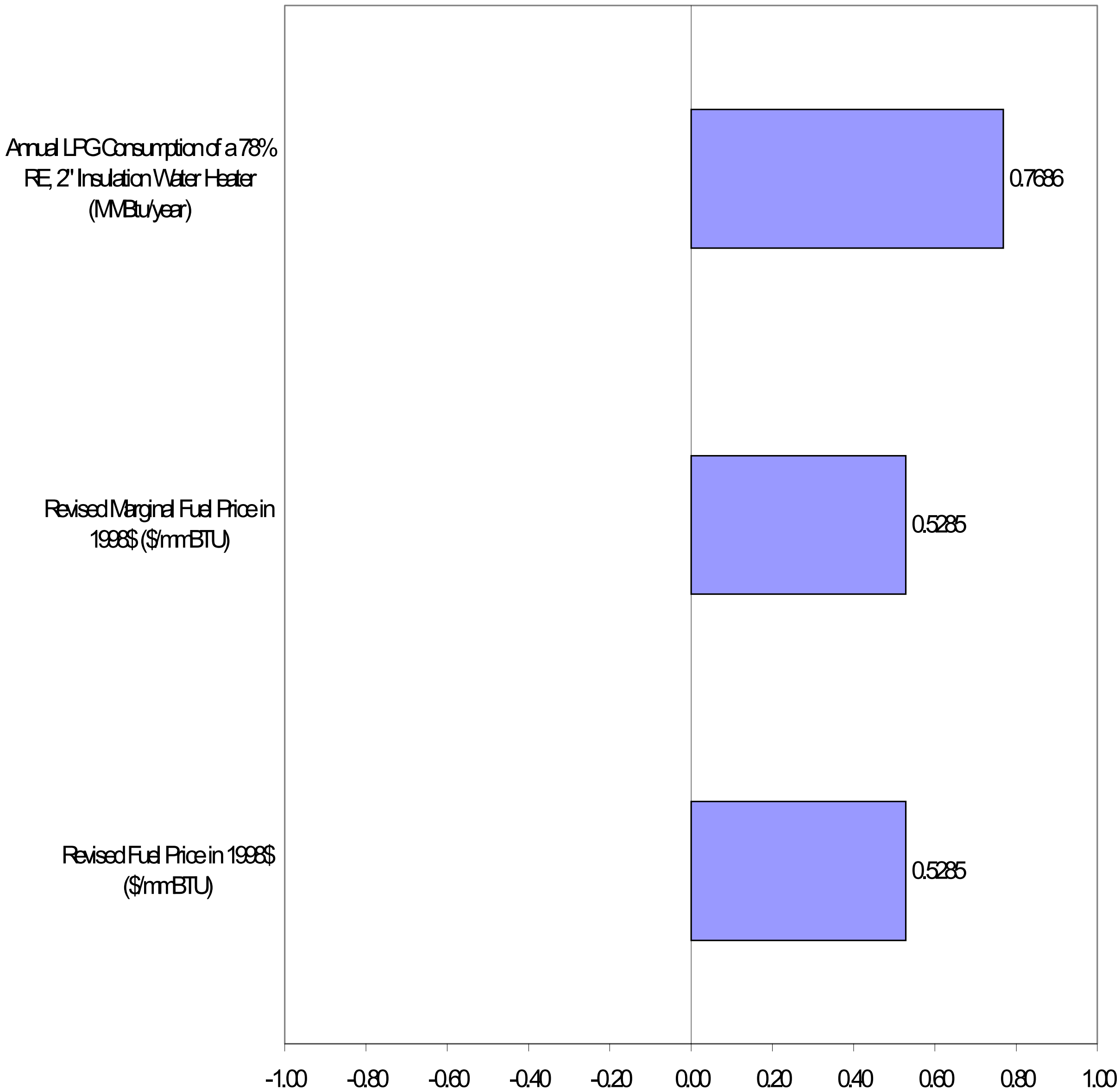

Figure 9.4.11 Importance of Input Parameters to Operating Cost for 78% RE 2" Insulation on LPG Water Heaters

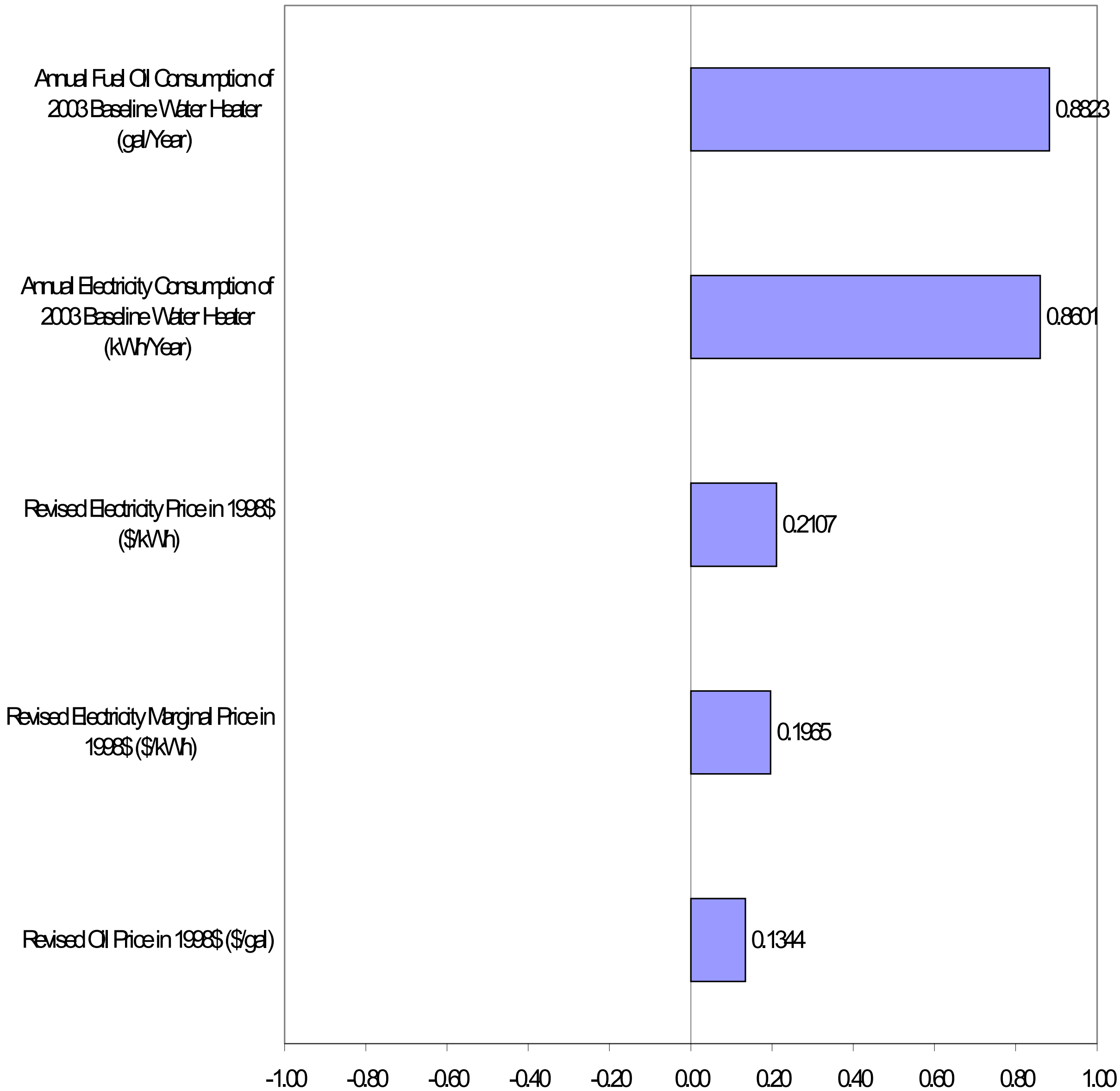

Figure 9.4.12 Importance of Input Parameters to Operating Cost for 2003 Baseline on Oil-Fired Water Heaters

9.5 EQUIPMENT COST MODULE

9.5.1 Introduction to Equipment Cost

Equipment cost represents the cost to a consumer to buy and install a water heater. It is the sum of the water heater's retail price, sales tax, and installation costs. Installation costs can also include delivery, removal, permits, and parts fees. Retail price is calculated from the manufacturer's cost multiplied by an overall markup.

The first half of this discussion addresses the typical existing baseline model in all standard sizes, that is, water heaters in use in 1998, for all sizes considered in the LCC. The 2003 baseline model is our projection of what baseline water heater models will look like in 2003 prior to any new energy-efficiency standards. It is the basis for the later description of design options that follows in Section 9.5.5.2.

9.5.2 Equation for Equipment Cost

Water heater equipment cost is calculated using the equation:

$$EquipCost_{option,\ size} = (MfrCost_{option,\ size}\ x\ Markup_{size})\ x\ (1 + SalesTax) + TotlInstCost_{option,\ size}$$

where:

MfrCost	=	cost to manufacture the water heater (1998$)
Markup	=	overall markup from manufacturer's cost to retail price
SalesTax	=	sales tax on water heater (%)
TotInstCost	=	total cost to install the water heater ($).

The markup is calculated for existing baseline models and is applied to all design options using the following ratio:

$$Markup_{size} = RetlPrice_{size} / MfrCost_{size}$$

where:

$RetlPrice_{size}$	=	current retail prices for existing baseline water heaters of a given size ($)

This markup is then applied to all design options.

Total installation cost is calculated as:

$$TotInstCost_{option,\ size} = InstCost_{size} + AddInstCost_{option}$$

where:

$InstCost$ = cost to install a baseline water heater of a particular size ($)

$AddInstCost$ = additional cost(s) to install water heaters with certain design options ($)

The additional installation cost is calculated as follows:

$$AddInstCost_{option} = AddElecCost_{option} + AddVentCost_{option} + AddRelineCost_{option} + AddInstCostfor3in + AddTubeCost_{option} + DrainPanCost_{option} + TempValCost_{option}$$

where:

$AddElecCost$ = additional cost of installing a new electric circuit for gas-fired (both natural gas and LPG)[a] water heaters with design options that require electricity ($)

$AddVentCost$ = additional cost of upgrading the vent connector for gas-fired (both natural gas and LPG) water heaters with RE greater than 78% ($)

$AddRelineCost$ = additional cost of relining masonry chimney for gas-fired (both natural gas and LPG) water heaters with RE greater than 80% ($)

$AddInstCostfor3in$ = additional installation cost for water heaters with 3" insulation ($)

$AddTubeCost$ = additional cost to install a burner tube extension for oil-fired water heaters with thicker insulation ($)

$DrainPanCost$ = additional cost to add a drain pan for water heaters with thicker insulation ($)

$TempValCost$ = additional cost to install a tempering valve for water heaters with thicker insulation ($)

[a] Water heaters fueled by natural gas and LPG are considered as one product class from the point of view of physical and efficiency characteristics. They are treated separately with respect to manufacturing cost, markup, retail price, and fuel price in the Life-Cycle Cost and subsequent analyses.

9.5.3 General Description of Key Variables

MfrCost is the manufacturing cost of producing a water heater. This cost is the sum of variable and fixed costs to the manufacturer. The variable costs are the sum of materials, labor, and overhead costs. The variable manufacturer cost is also called "full production cost." Fixed costs are the sum of the capital cost and the product design cost to convert to production of a new water heater design. The fixed manufacturer cost is sometimes called a conversion cost.

Markup is defined as the ratio between the retail price and the manufacturer's cost for baseline water heaters. The markup is different for different tank sizes. This is an overall markup; it may include several intermediate markups applied by a wholesaler or other intermediate sellers. See Chapter 7, Markups, for a full discussion of markups, both retail and manufacturers'.

SalesTax is the state, county, and/or local tax applied to a water heater at the point of sale.

RetlPrice is defined as the retail price of the water heater, paid directly by the customer. This price does not include installation costs or any other miscellaneous costs, such as delivery, removal, permit, and parts fees.

TotInstCost is the total installation cost for the water heater. It is the price paid directly by the customer to have the water heater installed, including additional charges for some design options.

InstCost is the installation cost of the baseline water heater. It is the price paid directly by the customer to have the water heater installed, including any miscellaneous costs such as delivery, removal, permit, and parts fees. It does not include the cost of adding a new electrical circuit and/or upgrading the venting system, as needed for some gas-fired (both natural gas and LPG) water heater design options.

AddInstCost is the additional installation cost to install an electric circuit and/or to upgrade the venting system of a gas-fired (both natural gas and LPG) water heater, or to install a burner tube extension for an oil-fired water heater with thicker insulation. (An additional cost is added for water heaters with 3" insulation for a subset of houses.)

AddElecCost is the additional cost of installing an electric circuit for a gas-fired (both natural gas and LPG) water heater when the design option includes an intermittent ignition device and a circulating pump, and there is no pre-existing electrical outlet near the water heater.

AddVentCost is the additional cost to upgrade an existing venting system to eliminate condensation problems from gas-fired (both natural gas and LPG) water heaters with design options that increase recovery efficiency. As discussed in the Engineering Analysis, Chapter 8, we consider design options that raise recovery efficiency to either 78 or 80% (for purposes of this analysis, DOE limits recovery efficiency to a maximum of 80%). For options that raise recovery efficiency to 78%, we added the cost of installing a type-B vent connector to some houses in the Northeast and Midwest to assure that the venting system operates correctly. For design options that raise recovery efficiency to 80%, we added, for some houses in the Northeast and Midwest with masonry chimneys, the costs of a type-B vent connector and relining of the masonry chimneys (see Appendix D-3).

AddTubeCost is the additional cost to install a burner tube extension for an oil-fired water heater with thicker insulation than the baseline unit.

DrainPanCost is the additional cost to add a drain pan for an electric or gas-fired water heater with thicker insulation than the original unit when the water heater is in a conditioned space without a slab-on-grade floor.

TempValCost is the additional cost to install a tempering valve on an electric or gas-fired water heater of a smaller size than the original unit when the water heater is in a household subject to space constraints and the new water heater setpoint is > 140EF.

9.5.4 Markup

The manufacturer-to-retail markup is defined as the ratio of the retail price to the manufacturer cost. Because the retail price and the estimated manufacturer cost differ for each fuel type and for each size (rated volume), the markup is different for each standard-size existing baseline model.

The manufacturer-to-retail markup was assumed to be constant for all design options for each standard size model. Thus, the retail price for any design was determined simply by multiplying its manufacturer cost by the derived markup for the existing baseline water heater of that size. Retail prices are for water heaters sold in 1998.

9.5.4.1 Data Sources

To determine a water heater's equipment cost, data were needed on manufacturing cost, retail price, installation cost, and sales tax. GAMA provided a range of water heater manufacturing costs for typical existing baseline models.[33] LBNL contracted with a consultant [15] recommended by GAMA to acquire additional data.

The Water Heater Price Database, which contains data collected from large retail chains and wholesale distributors, is the source of retail prices, sales tax, and installation costs (see Appendix B, Water Heater Price Database).

Markup, as used here, is retail price divided by manufacturing cost for existing baseline models. The retail prices for all standard-size existing baseline models are drawn from the Water Heater Price Database. A maximum six-year manufacturing warranty and no special design features are the criteria for including these models. Manufacturing costs for typical size water heaters were provided by GAMA.[34] Manufacturing costs for all other standard sizes of existing baseline water heaters are based on the manufacturing cost for the typical water heater plus (or minus) incremental costs for extra (or less) foam insulation and sheet metal. Because retail price and manufacturing cost vary by tank size and fuel type, so do markups.

9.5.4.2 Existing Baseline Retail Price

The retail price is defined as the retail outlet price paid directly by the customer for a water heater. This price does not include the installation cost or any other miscellaneous costs such as delivery, removal, permit, or parts fees. The retail price analysis is based on the Water Heater Price Database. The models selected for the analysis are baseline models with a six-year manufacturer warranty or less and no special design features. Table 9.5.1 presents the average, minimum, and maximum retail prices for the existing baseline models in all standard sizes. These data for electric, natural gas, and oil-fired are based on discrete values taken from the Water Heater Price Database. The data for LPG are approximated from LPG retail prices.

Table 9.5.1 Retail Price Data for Existing Baseline Water Heaters

Existing Baseline	Average Retail Price	Cost Uncertainty Range	
	Total *$*	Minimum *$*	Maximum *$*
Electric (30-gal)	188	97	370
Electric (40-gal)	187	110	302
Electric (50-gal)	193	128	385
Electric (65-gal)	346	210	429
Electric (80-gal)	394	297	552
Natural Gas (30-gal)	176	118	379
Natural Gas (40-gal)	167	115	276
Natural Gas (50-gal)	248	163	500
Natural Gas (75-gal)	546	350	900
LPG (30-gal)	285	235	323
LPG (40-gal)	289	199	355
LPG (50-gal)	357	265	397
LPG (75-gal)	682	507	759
Oil-Fired (32-gal)	446	410	619
Oil-Fired (50-gal)	446	410	619

9.5.4.3 Existing Baseline Manufacturing Cost

The typical existing baseline manufacturing cost data used in the analysis for the four fuel types are presented in Table 9.5.2.

Table 9.5.2 Total Manufacturing Cost Data for Typical Existing Baseline Water Heaters

Typical Existing Baseline	Average Total Costs	Cost Uncertainty Range	
	Total *$*	Minimum *$*	Maximum *$*
Electric (50-gal)	114	88	133
Natural Gas (40-gal)	112	86	130
LPG (40-gal)	145	124	164
Oil-Fired (32-gal)	139	125	153

As explained above, the manufacturing costs for the range of standard size water heaters considered in the LCC are based on the manufacturing costs for the typical existing baseline water heater plus (or minus) incremental costs for extra (or fewer) materials, i.e., foam insulation and sheet metal. Table 9.5.3 presents the calculated incremental costs for all standard-size existing baseline models.

Table 9.5.3 Total Manufacturing Cost Data for Standard-Size Existing Baseline Water Heaters

Rated Volume	Incremental Cost *$*	Average Total Cost *$*
Electric 30-gal	-7.78	106.08
Electric 40-gal	-2.83	111.67
Electric 65-gal	3.87	117.59
Electric 80-gal	7.39	123.20
Natural Gas 30-gal	-3.15	127.25
Natural Gas 50-gal	2.23	131.84
Natural Gas 75-gal	7.50	137.41
LPG 30-gal	-3.15	142.40
LPG 50-gal	2.23	145.94
LPG 75-gal	7.50	151.77
Oil-Fired 50-gal	66.88	206.12

9.5.4.4 Summary of Markup

Table 9.5.4 presents a summary of the markups for electric, natural gas, LPG, and oil-fired water heaters. A complete discussion of markups is provided in Chapter 7.

Table 9.5.4 Markups by Fuel Type and Tank Size

Fuel Type	Tank Size *gal*	Markup		
		Average	Minimum	Maximum
Electric	30	1.81	0.78	4.46
	40	1.70	0.84	3.44
	50	1.70	0.97	4.30
	65	3.00	1.53	4.62
	80	3.21	2.13	5.28
Natural Gas	30	1.44	0.86	3.69
	40	1.33	0.80	2.65
	50	1.95	1.12	4.31
	75	4.00	2.28	7.56
LPG	30	2.05	1.54	2.79
	40	2.04	1.31	2.93
	50	2.41	1.72	3.20
	75	4.26	3.21	5.53
Oil	32	3.53	2.74	4.77
	50	3.54	2.79	4.56

9.5.5 Manufacturing Cost

9.5.5.1 2003 Baseline Manufacturing Cost

The general methodology for determining the 2003 baseline manufacturing cost is as follows: 1) GAMA distributions of the existing baseline manufacturing cost are adjusted for the use of HFC-245fa. 2) These distributions of manufacturing costs are then modified to account for the different amounts of steel and insulation used in the other standard sizes (see Chapter 6, Manufacturing Cost

Assessment). We recalculate the insulation, sheet metal, and blowing agent costs to reflect the slightly thicker insulation of baseline water heaters with HFC-245fa insulation.

As explained in the Engineering Analysis, Chapter 8, the HCFC-141b blowing agent currently in use will be replaced by the year 2003. Because new energy-efficiency standards are expected to take effect about the same time as the phase-out of HCFC-141b, the baseline model for our analysis uses one of the leading alternative blowing agents, HFC-245fa. As also discussed in Chapter 8, future gas-fired and LPG water heaters must be able to resist ignition of flammable vapors, for health and safety reasons. The new 2003 baseline models for gas-fired and LPG water heaters therefore includes the cost of design changes to resist ignition of flammable vapors.

9.5.5.2 Incremental Manufacturing Costs for Design Options

The incremental manufacturing costs for design options were supplied primarily by GAMA. No data were provided for 2.5" Insulation or Plastic Tank for electric water heaters; 2.5" Insulation, and Side Arm for gas-fired water heaters; nor any of the design options for oil-fired water heaters. We obtained the missing data from consultants.[15, 35]

Design Option Combinations. Many combinations of design options were initially analyzed (see Appendix D-5 for the full listing) . The selected designs consist of combinations of basic design options. Chapter 8 explains in detail the selection of design option combinations. A list of selected the design option combinations is shown in Table 9.1.1 through 9.1.4 at the beginning of this chapter.

For each design option combination, incremental manufacturer costs were calculated from costs of each design component as explained in Chapter 8. The range of incremental total cost for some of the design options were provided by GAMA.[34] Some of the costs (Plastic Tank and Side Arm) were calculated using ranges provided by consultants.[15] Because these uncertainty values were for existing models, the next step was to recalculate the data to apply to the 2003 baseline and design options.

Incremental Manufacturing Costs. The LCC analysis uses individual design options that are then grouped together in combinations according to the results of the engineering analysis. This analytic procedure requires incremental manufacturing costs for individual design options.

The distribution of manufacturing costs for design options were provided by GAMA as cumulative frequency tables. GAMA data only applied to 50-gal electric water heaters and to 40-gal natural gas water heaters. These data are used as the basis for the calculation of incremental manufacturing costs.

The same incremental costs for Plastic Tank and Tank Bottom Insulation design options were applied to all standard sizes of water heaters. The distribution of the manufacturing costs for design options not provided by GAMA are based on data provided by consultants. [15]

For a discussion of how we transformed cumulative distributions into frequency distributions, see Appendix E-3.

Table 9.5.5 lists the incremental costs for the individual design options for the typical (50-gal) electric water heater.

Table 9.5.5 Incremental Costs for Electric Water Heaters (50-gal)

Design Option	Average Incremental Manufacturing Cost $
Heat Traps	3.56
Tank Bottom Insulation	7.49
2" Insulation	30.01
2.5" Insulation	41.55
Plastic Tank	65.52
3" Insulation	79.91

Table 9.5.6 lists the incremental costs for the individual design options for the typical (40-gal) natural gas water heater.

Table 9.5.6 Incremental Costs for Natural Gas Water Heaters (40-gal)

Design Option	Average Incremental Manufacturing Cost $
Heat Traps	2.30
78% RE	9.69
78% RE, 2" Insulation	25.61
78% RE, 2.5" Insulation	37.11
80% RE, 2" Insulation	25.61
80% RE, 2.5" Insulation	37.11
80% RE, 3" Insulation	51.65
Side Arm	186.89

Table 9.5.7 lists the incremental costs for the individual design options for the typical (40-gal) LPG water heater.

Table 9.5.7 Incremental Costs for LPG Water Heaters (40-gal)

Design Option	Average Incremental Manufacturing Cost $
Heat Traps	2.31
78% RE	9.73
78% RE, 2" Insulation	25.55
78% RE, 2.5" Insulation	37.09
80% RE, 2" Insulation	25.55
80% RE, 2.5" Insulation	37.09
80% RE, 3" Insulation	51.64
Side Arm	186.96

Table 9.5.8 lists the incremental costs for the individual design options for the typical (32-gal) oil-fired water heater.

Table 9.5.8 Incremental Costs for Oil-Fired Water Heaters (32-gal)

Design Option	Average Incremental Manufacturing Cost $
Heat Traps	5.35
2" Insulation	13.99
2.5" Insulation	20.86
3" Insulation	27.51
78% RE	37.92
Interrupted Ignition	16.39
Increased HX Area	106.00

9.5.6 Sales Tax

Sales taxes range from a minimum of 0% (some states have no sales tax) to a maximum of 9.00%, with an average of 5.22%. See Retail Prices, Chapter 5, for a detailed discussion.

9.5.7 Installation Cost

The installation cost of a water heater is the price paid by a customer to have the water heater installed. This price does not include the retail price but does include other miscellaneous costs such as delivery, removal, permit, and parts fees.

Installation costs are included in the Water Heater Price Database. The baseline models were selected for our analysis of installation costs using the same criteria used for the retail price determination: a maximum six-year manufacturing warranty and no special design features. Table 9.5.8 presents the installation cost data for all standard sizes of the baseline models.

Table 9.5.9 Existing Baseline Water Heaters for Installation Cost Data

Existing Baseline	Average Installation Cost	Cost Uncertainty Range	
	Total $	**Minimum $**	**Maximum $**
Electric (30-gal)	152	65	234
Electric (40-gal)	148	65	231
Electric (50-gal)	160	65	269
Electric (65-gal)	140	75	170
Electric (80-gal)	138	90	262
Natural Gas (30-gal)	162	65	258
Natural Gas (40-gal)	162	65	292
Natural Gas (50-gal)	178	30	418
Natural Gas (75-gal)	207	90	287
LPG (30-gal)*	162	65	258
LPG (40-gal)	162	65	292
LPG (50-gal)	178	30	418
LPG (75-gal)	207	90	287
Oil-Fired (32-gal)	491	363	771
Oil-Fired (50-gal)	491	363	771

*Assumes the same costs as natural gas water heaters

9.5.8 Equipment Cost Results

9.5.8.1 Electric Water Heater Equipment Costs

Table 9.5.10 lists the average manufacturing and total installed costs for the 2003 baseline and the design option combinations for all sizes of electric water heaters. Total installed cost is the total cost to the customer, i.e., the sum of retail price, sales tax, and installation costs.

Table 9.5.10 Equipment Costs for Electric Water Heaters (All Sizes)

Design Option		Average Manufacturing Costs $	Average Retail Price $	Average Total Installed Costs $
0	2003 Baseline	114	220	385
1	Heat Traps	117	227	392
2	Tank Bottom Insulation	121	235	400
3	2" Insulation	143	278	446
4	2.5" Insulation	155	300	486
5	Plastic Tank	179	347	535
6	3" Insulation	193	375	615

Figure 9.5.1 shows, for all standard sizes, the difference in total installed cost for each design option compared to the 2003 baseline for electric water heaters. Variations in total installed cost include variations in manufacturing cost, markup, and installed cost. An additional installation cost is added for water heaters with 3" insulation for a fraction of housing units to account for the removal and re-installation of doorjambs. This is shown in the figure for design options that include 3" insulation. In general, design options with higher efficiencies show a wider spread in total incremental installed cost.

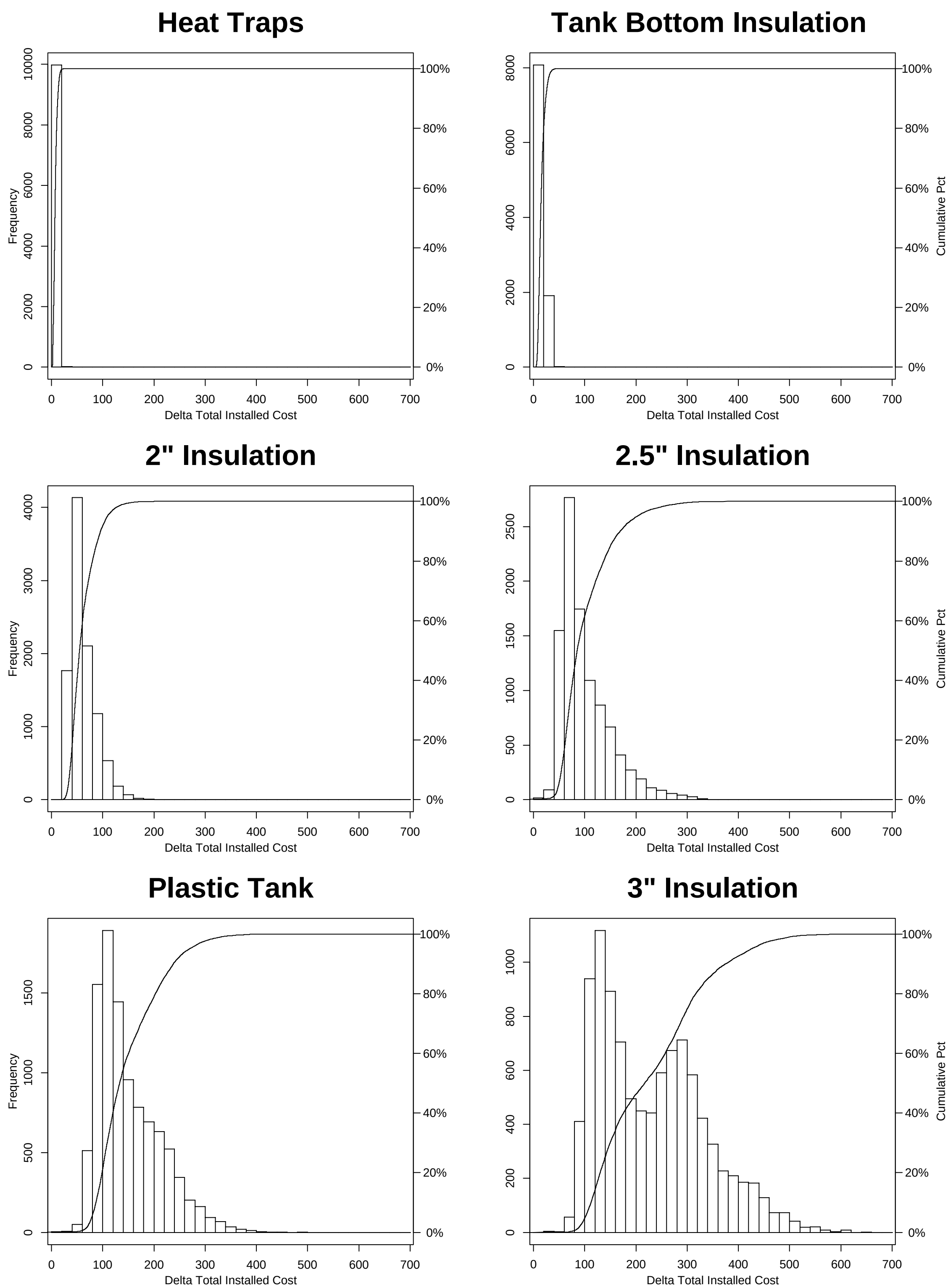

Figure 9.5.1 Difference in Total Installed Cost by Design Option for Electric Water Heaters

9.5.8.2 Natural Gas Water Heater Equipment Costs

Table 9.5.11 lists the average manufacturing and total installed costs for the 2003 baseline and the design option combinations for all sizes of natural gas water heaters; total installed cost is the final total cost to the customer, i.e., retail price, sales tax, plus installation costs.

Table 9.5.11 Equipment Costs for Natural Gas Water Heaters (All Sizes)

Design Option		Average Manufacturing Costs $	Average Retail Price $	Average Total Installed Costs $
0	2003 Baseline	166	264	443
1	Heat Traps	168	267	447
2	78% RE	176	279	474
3	78% RE, 2" Insulation	191	304	501
4	78% RE, 2.5" Insulation	203	323	531
5	80% RE, 2" Insulation	191	304	568
6	80% RE, 2.5" Insulation	203	323	597
7	80% RE, 3" Insulation	218	346	664
8	Side Arm	353	561	924

Figure 9.5.2 shows, for all standard sizes, the difference in total installed costs for each design option compared to the 2003 baseline for natural gas water heaters. Variations in total installed cost include variations in manufacturing cost, markup, and installed cost. An additional installation cost is added for water heaters with 3" insulation for a fraction of housing units to account for the removal and re-installation of doorjambs. This is shown in the figure for design options that include 3" insulation. In general, design options with higher efficiencies have a wider spread in total installed cost.

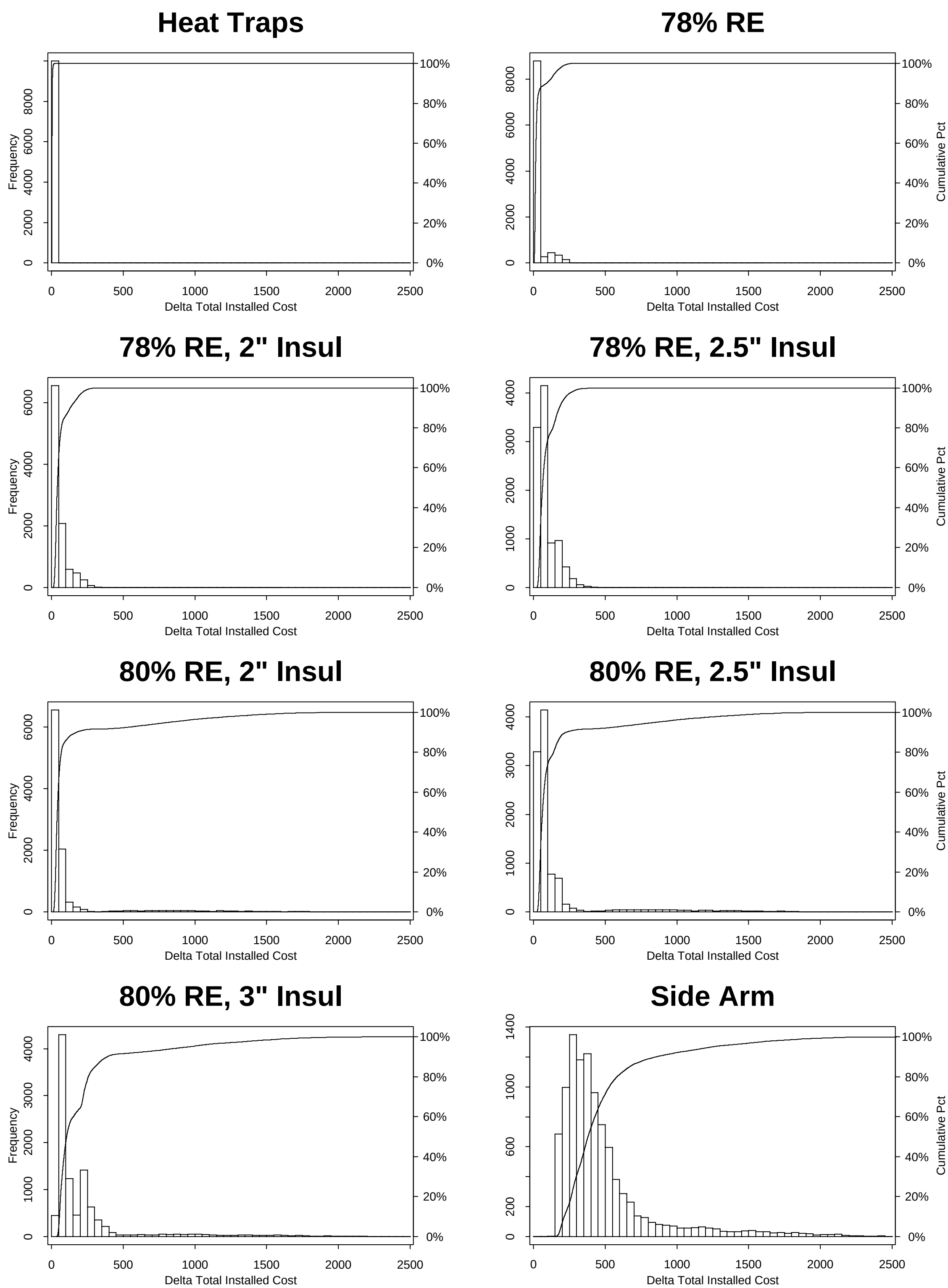

Figure 9.5.2 Difference in Total Installed Costs by Design Option for Natural Gas Water Heaters

9.5.8.3 LPG Water Heater Equipment Costs

Table 9.5.12 lists the average manufacturing and total installed costs for the 2003 baseline and the design option combinations for all sizes of LPG water heaters; total installed cost is the final total cost to the customer, i.e., the sum of retail price, sales tax, and installation costs.

Table 9.5.12 Equipment Costs for LPG Water Heaters (All Sizes)

Design Option		Average Manufacturing Costs $	Average Retail Price $	Average Total Installed Costs $
0	2003 Baseline	181	392	578
1	Heat Traps	183	397	583
2	78% RE	190	413	616
3	78% RE, 2" Insulation	206	448	653
4	78% RE, 2.5" Insulation	218	473	693
5	80% RE, 2" Insulation	206	448	729
6	80% RE, 2.5" Insulation	218	473	769
7	80% RE, 3" Insulation	232	504	849
8	Side Arm	367	798	1192

Figure 9.5.3 shows, for all standard sizes, the difference in total installed costs for each design option compared to the 2003 baseline for natural gas water heaters. Variations in total installed cost include variations in manufacturing cost, markup, and installed cost. An additional installation cost is added for water heaters with 3" insulation for a fraction of housing units to account for the removal and re-installation of doorjambs. This is shown in the figure for design options that include 3" insulation. In general, design options with higher efficiencies have a wider spread in total installed cost.

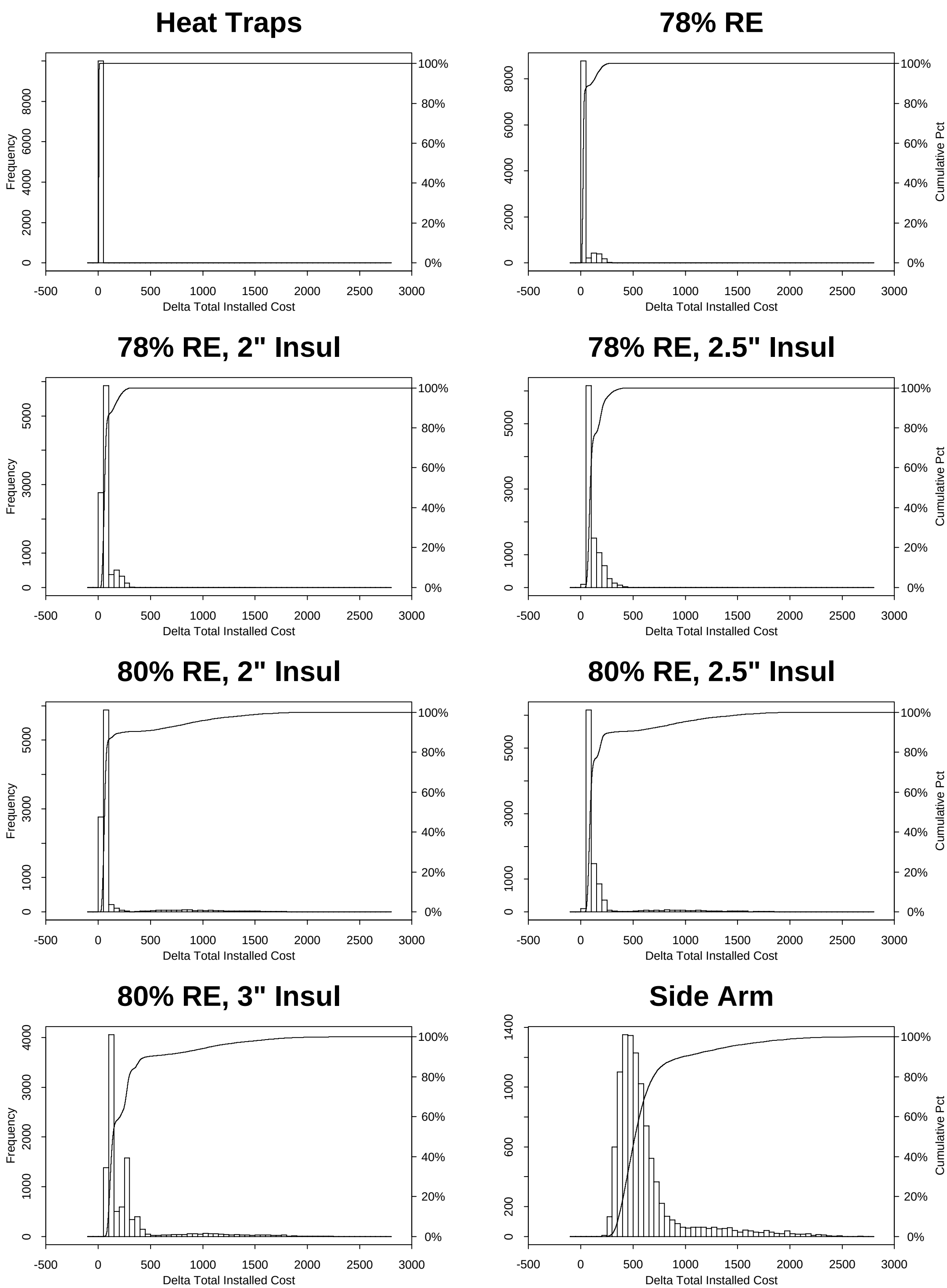

Figure 9.5.3 Difference in Total Installed Costs by Design Option for LPG Water Heaters

9.5.8.4 Oil-Fired Water Heater Equipment Costs

Table 9.5.13 lists the average manufacturing and total installed costs for the 2003 baseline and the design option combinations for all sizes of oil-fired water heaters; total installed cost is the final total cost to the customer, i.e., retail price, sales tax, plus installation costs.

Table 9.5.13 Equipment Costs for Oil-Fired Water Heaters (All Sizes)

Design Option		Average Manufacturing Costs $	Average Total Installed Costs $
0	2003 Baseline	155	1128
1	Heat Traps	163	1158
2	2" Insulation	175	1227
3	2.5" Insulation	185	1262
4	3" Insulation	192	1299
5	78% RE	230	1443
6	Interrupted Ignition	246	1506
7	Increased HX Area	316	1769

Figure 9.5.4 shows, for all standard sizes, the difference in total installed costs for each design option compared to the 2003 baseline for oil-fired water heaters. Variations in total installed cost include variations in manufacturing cost, markup, and installed cost. In general, design options with higher efficiencies have a wider spread in total installed cost.

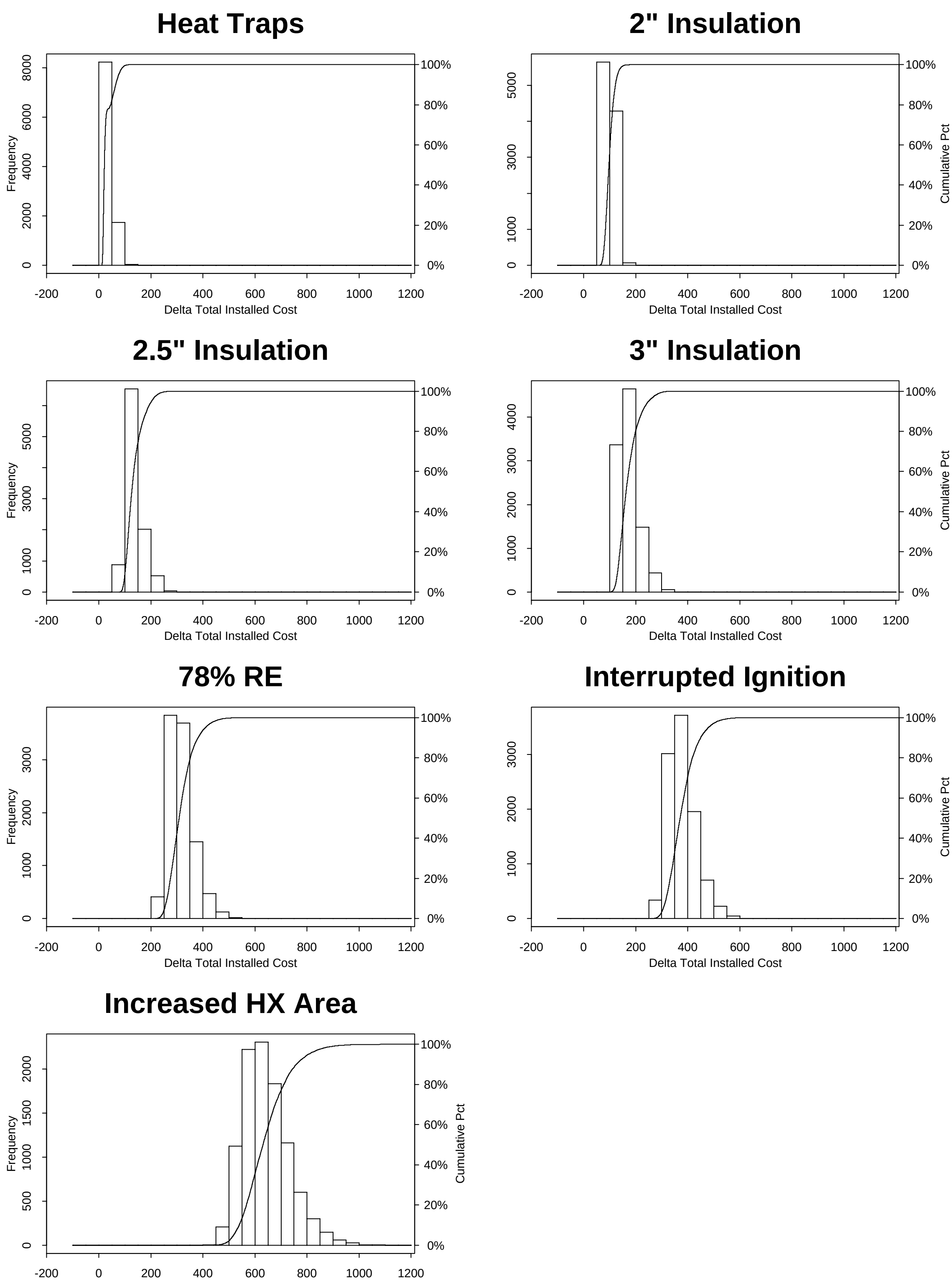

Figure 9.5.4 Difference in Total Installed Costs by Design Option for Oil-Fired Water Heaters

9.5.9 Importance Analysis

The following four input importance charts (Figures 9.5.5 through 9.5.8) show the results of the importance analysis for total installed costs at Trial Standard Level 3 for electric, natural gas, LPG, and oil-fired water heaters. Figure 9.5.5 shows the rank-order correlation of input variables with the difference in total installed cost for the 2.5" Insulation design option on electric water heaters. Figures 9.5.6 and 9.5.7 show the same for 78% RE and 2" Insulation on natural gas and LPG water heaters, respectively. Figure 9.5.8 shows the rank-order correlation for the 2003 Baseline on oil-fired water heaters. Variables are ordered with maximum correlation coefficients, positive or negative, on top and minimum coefficients on the bottom. For electric, natural gas-fired, and LPG water heaters, overall markup is the input which is most important in determining the total installed cost. For oil-fired water heaters, installation cost is the most important input to the total installed cost.

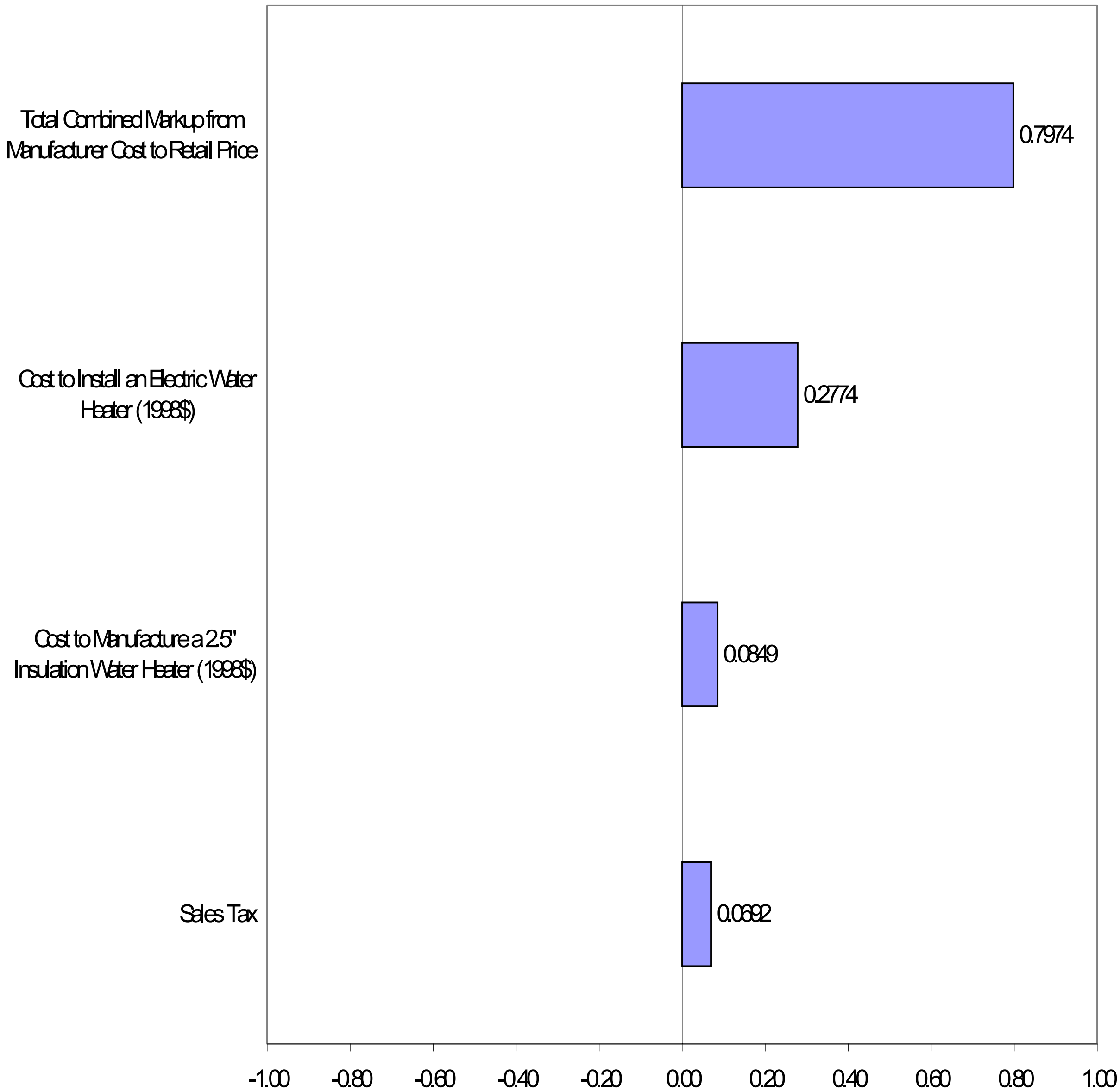

Figure 9.5.5 Importance of Input Variables to Total Installed Cost for 2.5" Insulation on Electric Water Heaters

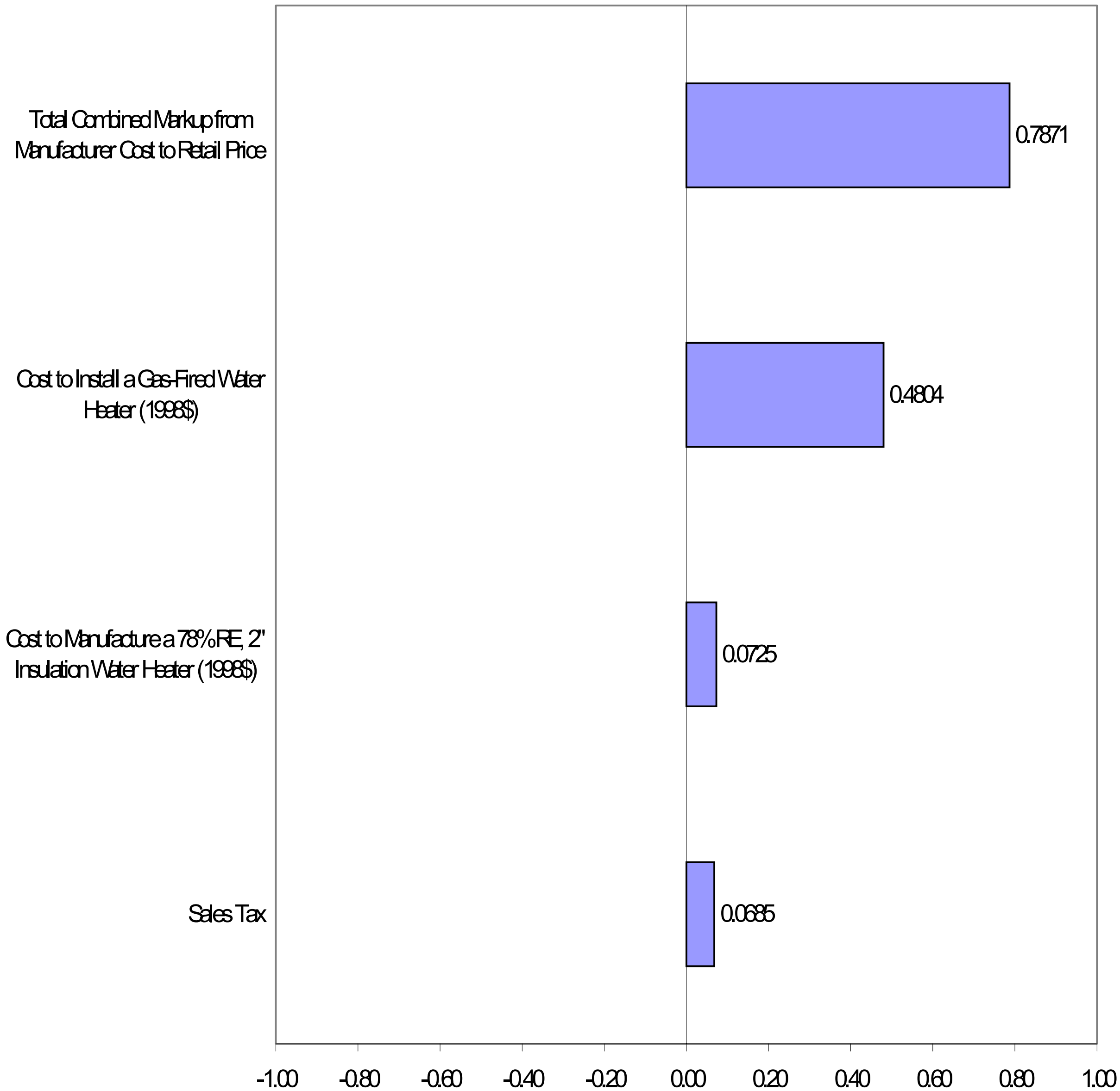

Figure 9.5.6 Importance of Input Variables to Total Installed Cost for 78% RE and 2" Insulation on Natural Gas Water Heaters

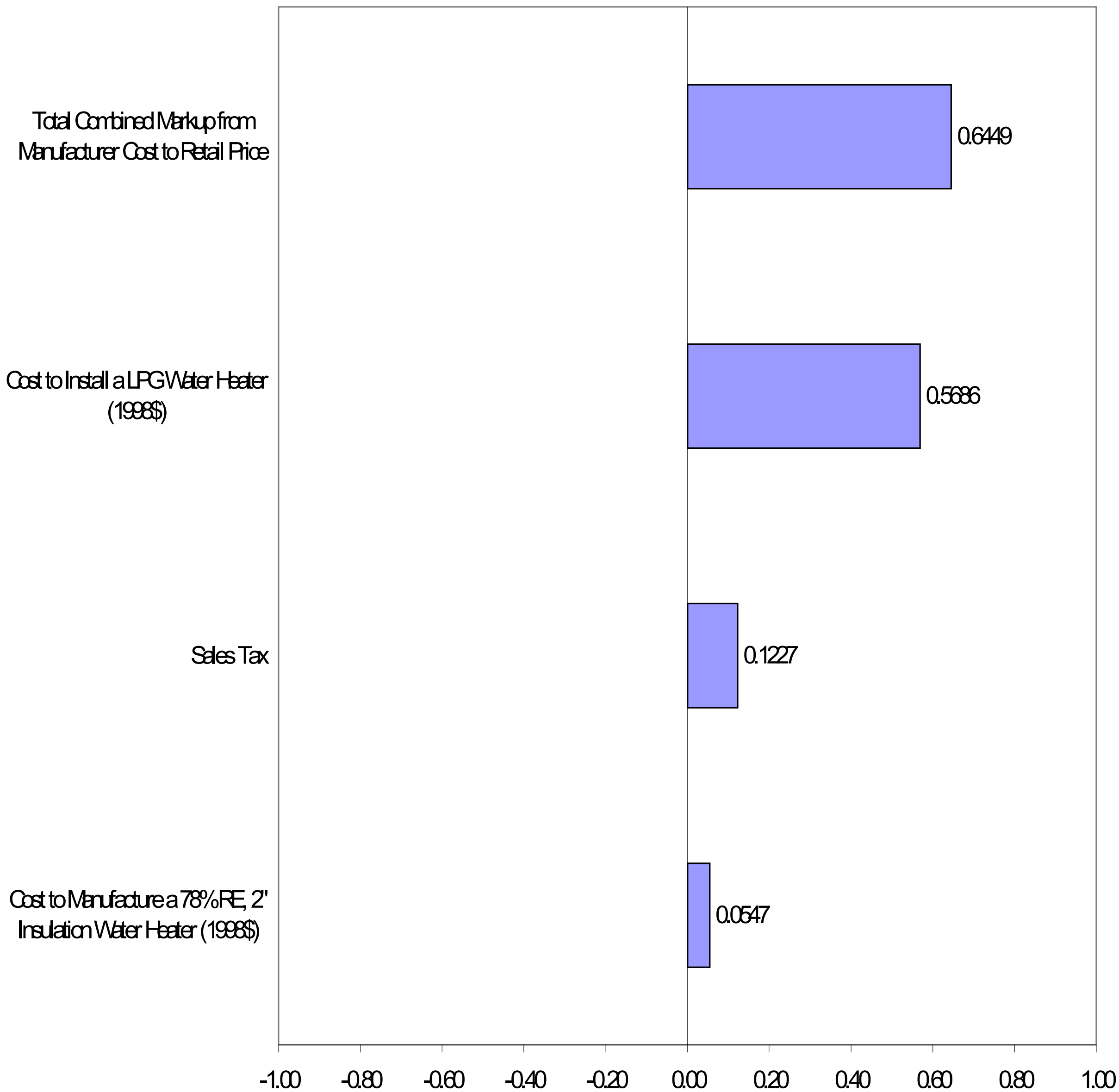

Figure 9.5.7 Importance of Input Variables to Total Installed Cost for 78% RE and 2" Insulation on LPG Water Heaters

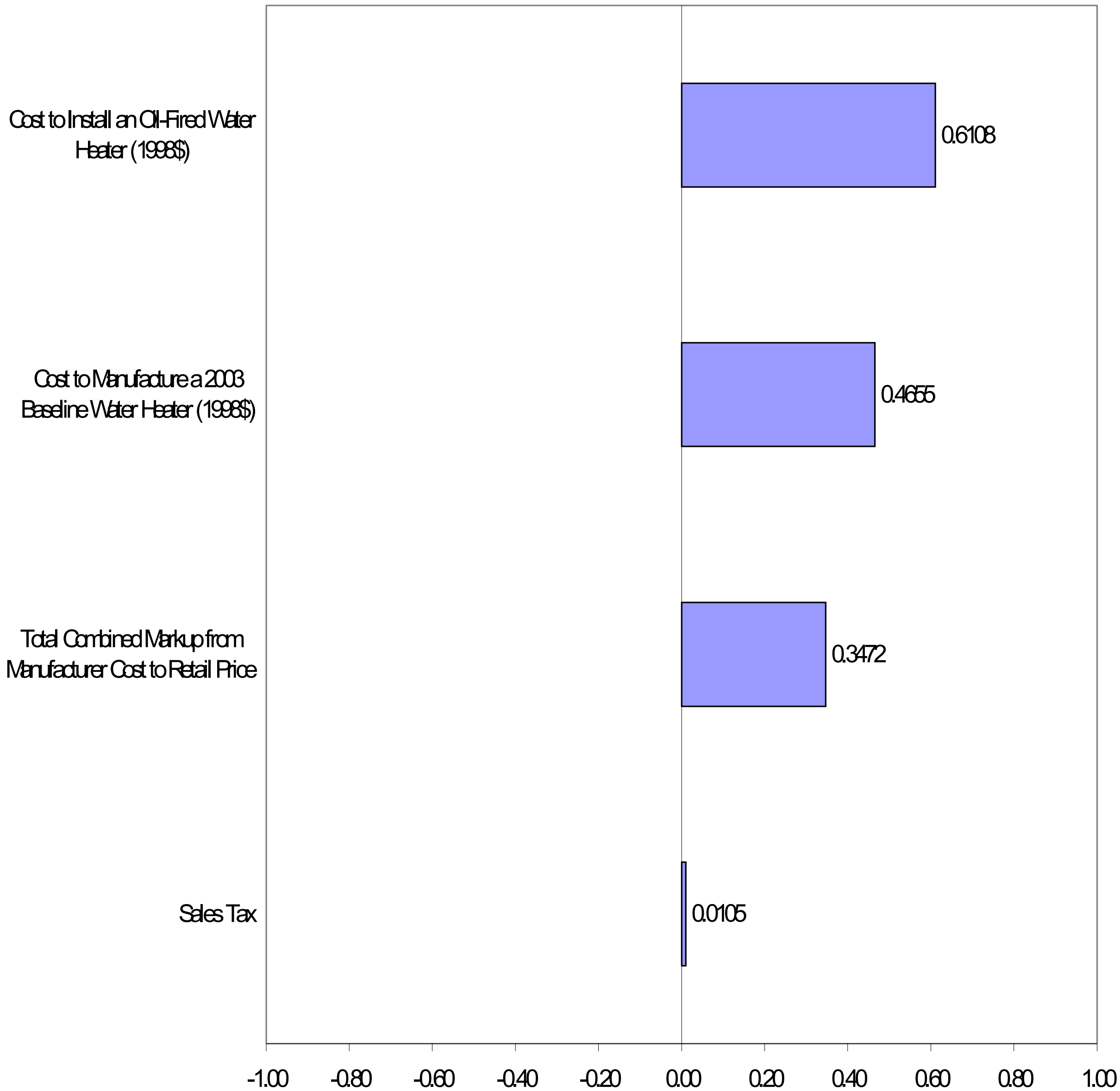

Figure 9.5.8 Importance of Input Variables to Total Installed Cost for 2003 Baseline on Oil-Fired Water Heaters

9.6 LIFE-CYCLE COST MODULE

9.6.1 Introduction

Life-cycle cost is defined as the total cost a consumer pays during the lifetime of a water heater, including purchase price and operating expenses (which include energy expenditures). Future operating expenses are discounted to the time of purchase and summed over the water heater's lifetime.

9.6.2 Equations and General Descriptions for LCC and Payback

Life-cycle cost is defined by the following equation:

$$LCC_{option} = EquipCost_{option} + NPV(D_{rate}, OprCost_{year,option}, Lifetime)$$

where:

EquipCost	=	cost of buying and installing a water heater ($)
	=	(Mfr. Cost * Markup) × (1 + sales tax) + (installation cost)
options	=	one of six design options for electric water heaters; one of eight design options for natural gas and LPG water heaters;[a] and one of seven for oil-fired water heaters.
NPV	=	Net present value ($) is defined by the following equation:

$$NPV = \sum_{year=1}^{Lifetime} \frac{OprCost_{year}}{\left(1 + D_{rate}\right)^{year}}$$

D_{rate}	=	Discount rate (real) (%)
OprCost	=	cost of operating a water heater ($/year)
	=	(energy usage) × (energy price) + (maintenance cost)
Lifetime	=	Lifetime of water heater (years)

[a] Water heaters fueled by natural gas and LPG are considered as one product class from the point of view of physical and efficiency characteristics. They are treated separately with respect to manufacturing cost, markup, retail price, and fuel price in the Life-Cycle Cost and subsequent analyses.

9.6.3 General Description of Key Variables

EquipCost is defined as the cost associated with buying and installing a water heater. This includes the cost of the water heater plus sales tax, installation charges, and, if the water heater is being replaced, charges for the removal of the old water heater.

NPV (**Net Present Value**) is the present-day value of a future stream of expenditures or earnings.

$\mathbf{D_{rate}}$ is defined as the rate at which future expenditures are discounted to establish their present value. A distribution of discount rates was derived to represent the variability in financing methods consumers use in purchasing appliances. The resulting distribution of discount rates is used to calculate a distribution of life-cycle costs for water heaters.

Consumers purchase appliances separately or as part of new homes. Purchases through retail vendors may be paid by cash, credit cards, or retailer loans. Whirlpool Corporation indicated that approximately 40% of white goods are purchased in cash, 35% with credit cards, and 25% with retailer loans. The same manufacturer indicated that 25% of appliance purchases are for new homes. (For water heaters, it is estimated that purchases for new homes are currently about 20%.) The method of purchase use is assumed to indicate the source of funds and type of financing used by these consumers.

We estimated a range of future interest rates that can reasonably be applied to different types of consumer savings or financing.

For new housing, the estimated nominal mortgage rate ranges from 5 to 8%, the derived after-tax rate is based on a tax of 28%, and an inflation rate of 2% is subtracted from the total. The result is a range of real mortgage rates from 1.60 to 3.76%. (Example: 5% * (100%-28%) - 2% = 1.60%)

For cash, the minimum interest rate is 0%. This rate applies to consumers making cash purchases without withdrawing from savings accounts. For the maximum rate, the opportunity cost is represented by the interest that could have been earned in a savings account. The historical nominal maximum savings rate ranged from 4.5 to 5.5% from 1970 to 1986 (real rates of -8.27 to +3.58%). A real rate of 3% was selected as of the maximum.

The interest rates for retailer loans and credit cards are assumed to have the same range. The minimum credit card rate is taken as 6% real. Introductory rates on some credit cards today are 5.9% nominal, but after the introductory period (often six months), the rate can increase sharply. Maximum rates are more than 20% nominal. However, if the consumer pays with a credit card and the balance is paid in less than the life of the water heater, then the effective interest rate is lower than the nominal credit card rate. The current assumption is a range of 6 to 15% real.

DOE recognizes that other factors might be considered in the estimation of real consumer discount rates, such as the actual impacts of appliance purchases on consumer savings, indebtedness, or consumption, and the expressed or imputed consumer preferences for obvious payment methods.

Although such data, if it were to become available, may provide a stronger analytical basis for DOE's choice of discount rates, it is considered unlikely that such data would have a significant effect on the range of values considered in the current analysis.

Figure 9.6.1 shows the distribution of real discount rates, ranging from 0 to 15%, with a mean of 6%.

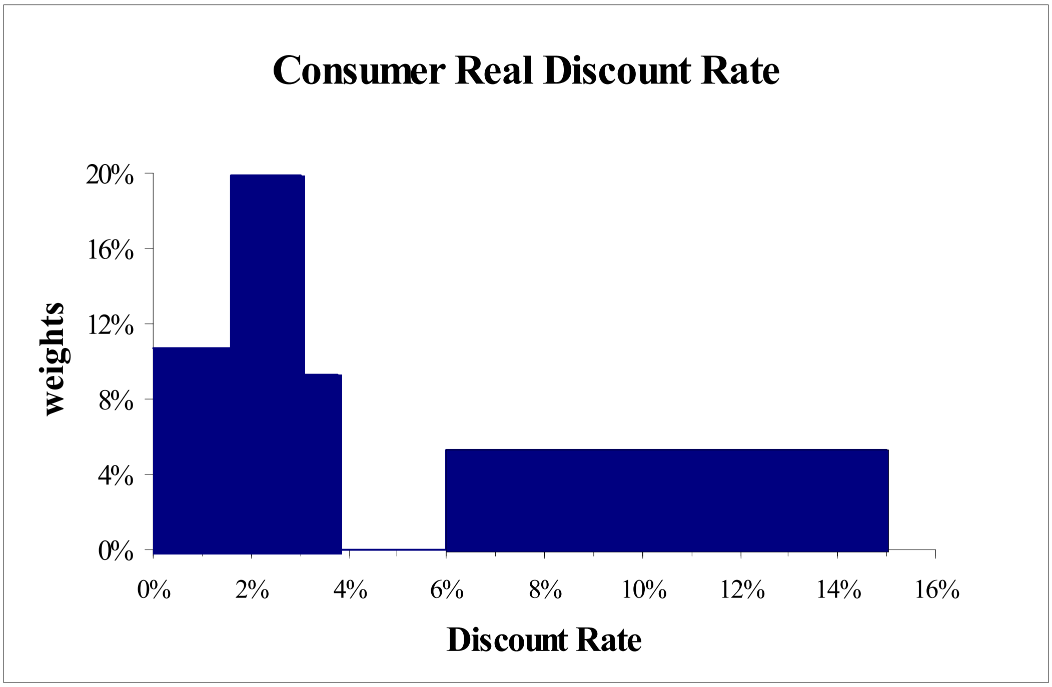

Figure 9.6.1 Distribution of Consumer Real Discount Rates

OprCost is defined as the annual expenditure necessary to keep a water heater operating. It has two parts: fuel and maintenance. Fuel costs are calculated by multiplying annual water heater energy use by the energy price paid by the household. Maintenance costs are repair charges or the cost of a service contract.

Lifetime is the period of time the water heater will provide service. Table 9.6.1 shows lifetimes for water heaters by fuel type.[4] LPG and oil water heaters are assumed to have the same distribution of lifetimes as natural gas water heaters.

Table 9.6.1 Water Heater Lifetimes by Fuel Type

Fuel Type	Lifetime *(years)*		
	Minimum	**Average**	**Maximum**
Electric	6	14	21
Natural Gas	5	9	13
LPG and Oil	5	9	13

The simple payback period measures the amount of time needed to recover the additional premium that a consumer pays for increased efficiency. This investment is recovered through reductions in operating costs.

The payback period equation can be expressed as:

$$Payback_{option} = \frac{EquipCost_{option} - EquipCost_{base}}{OprCost_{base} - OprCost_{option}}$$

where:

base = the typical 2003 baseline design

Numerically, the simple payback period is the ratio of the increase in purchase (and installation) price to the decrease in annual operating expenditures (including maintenance). The comparisons are made from replacing the 2003 baseline water heater with a water heater incorporating another design option. Payback periods are expressed in years. A payback period of three years means that the increased purchase price for the energy efficient water heater is equal to three times the value of reduced operating expenses in the year of purchase; in other words, the increased purchase price is recovered in approximately three years because of lower operating expenses. Payback periods greater than the life of the product mean that the increased purchase price is never recovered in reduced operating expenses.

9.6.4 Life-Cycle Cost and Payback Results

9.6.4.1 Electric Water Heaters

Table 9.6.2 lists the portion of the population that benefits, in terms of reduced life-cycle cost, from each energy-efficiency design option for electric water heaters. The average LCC savings and median payback are also shown.

Table 9.6.2 Life-Cycle Cost and Payback for Electric Water Heaters

Design Option		Fraction of Population Benefitting *%*	Average LCC Savings *$*	Median Payback *yrs*
1	Heat Traps	92	31	1.79
2	Tank Bottom Insulation	90	36	2.92
3	2" Insulation	68	32	6.47
4	2.5" Insulation	59	23	7.43
5	Plastic Tank	38	-21	10.97
6	3" Insulation	26	-82	14.37

Figure 9.6.2 together with Table 9.6.3 present summary life-cycle cost information for electric water heaters. Each bar refers to a specific design option. The bar's height above the horizontal axis shows the percentage of households that have a life-cycle savings. Conversely, the portion of the bar below the horizontal axis shows the percentage of households that have a life-cycle net cost. As the design options increase energy efficiency and cost, the bars show a greater fraction of the population having net costs. The positive and negative portions of the bars are shaded to show three ranges: significant savings; significant costs; and no significant change. A change of less than two percent of the average baseline life-cycle cost is considered insignificant. The average baseline life-cycle cost is included as a reference point. For the households benefitting by a design option, the table shows the average and maximum savings for that fraction of the population and also the average and maximum costs for the corresponding disadvantaged fraction of the population.

Table 9.6.3 Percent of Sample Having Net Savings or Costs for Electric Water Heaters

Population		Heat Traps	Tank Bottom Insulation	2 Inch Insulation	2.5 Inch Insulation	Plastic Tank	3 Inch Insulation
Significant Savings	% of sample	15%	21%	27%	30%	19%	14%
	Avg Savings	$84	$90	$111	$133	$139	$149
	Max Savings	$310	$451	$608	$788	$837	$761
Insignificant (a)	% of sample	85%	78%	70%	56%	46%	29%
Significant Cost	% of sample	0.06%	0.10%	4%	15%	35%	56%
	Avg Cost	$80	$72	$76	$121	$124	$180
	Max Cost	$127	$92	$176	$691	$730	$756
Total (100%)	Avg Savings	$31	$36	$32	$23	-$21	-$82

(a) cost or savings < 2% of average baseline LCC [$56]

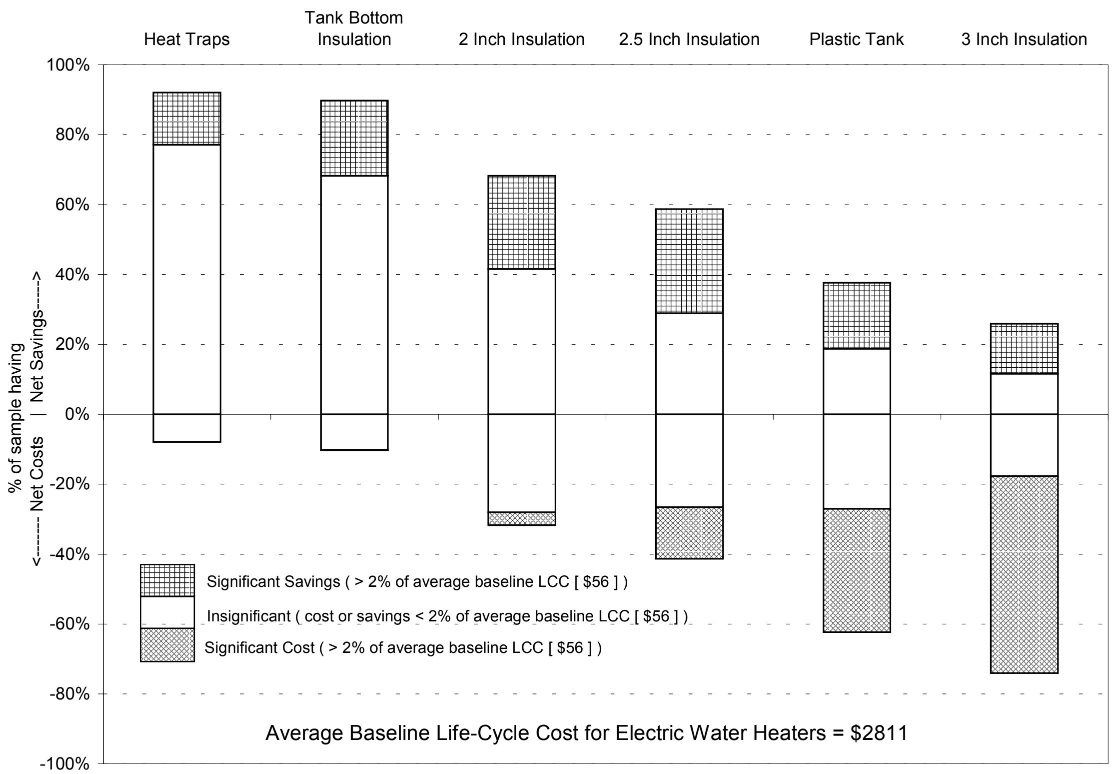

Figure 9.6.2 Percent of Sample Having Net Savings or Costs for Electric Water Heaters

Figure 9.6.3 shows the cumulative frequency of differences in LCC by design option for electric water heaters. The percentages of the population that do and do not benefit are also shown on the graph. Note that a negative difference in life-cycle cost for a given design option indicates a savings. The width of the plot shows the spread of savings in the population. In general, the design options with higher efficiencies tend to show a wider spread of LCC differences in the population.

Figure 9.6.4 shows the cumulative frequency of payback period by design option. The percent of population that would have a payback less than or equal to three years is indicated. A three-year payback period was chosen because it was assumed that design options that satisfy this criterion are most likely to be included in the proposed DOE efficiency standard. In general, design options with higher efficiencies tend to show a wider spread of payback period in the population.

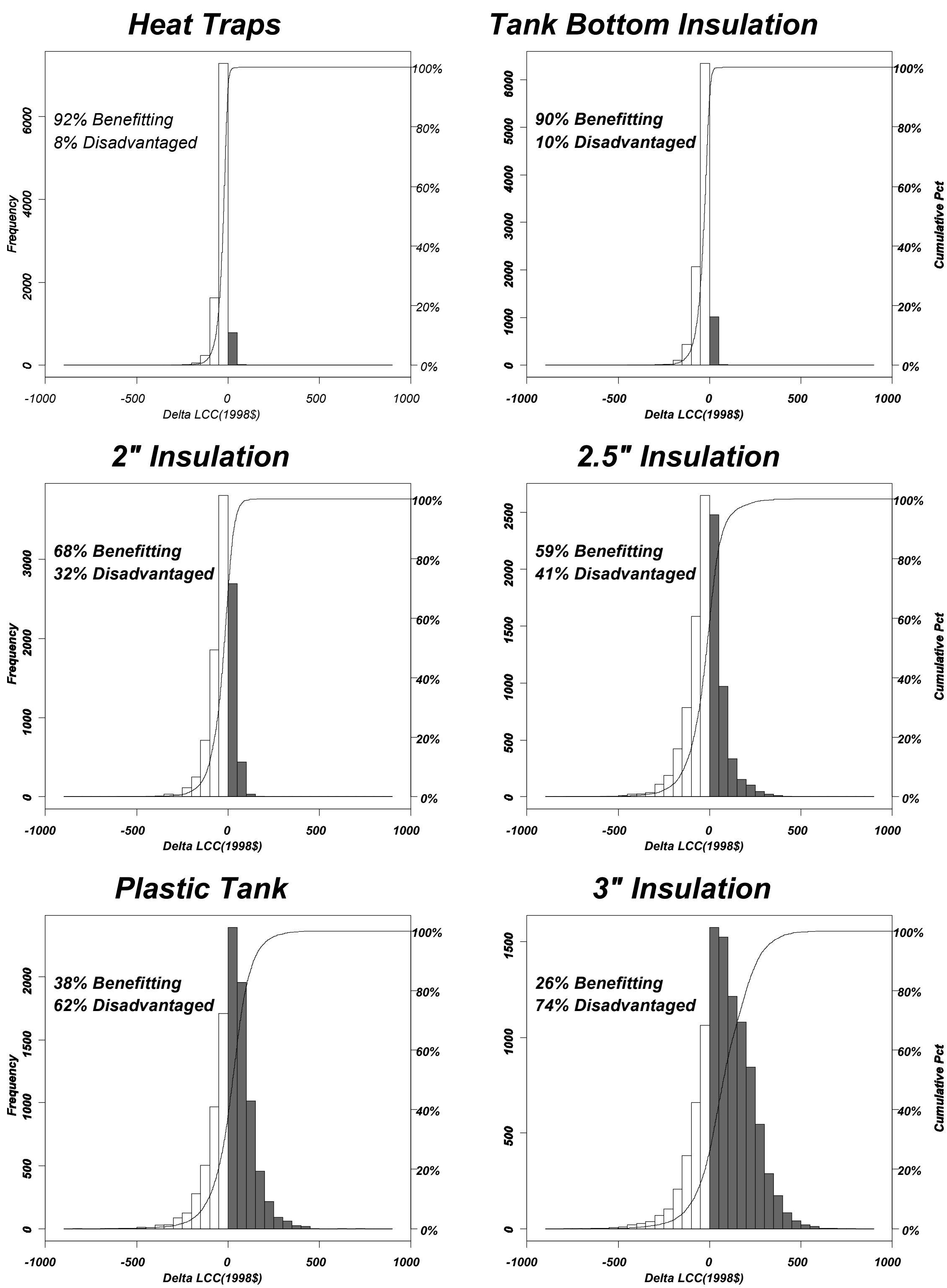

Figure 9.6.3 Difference in Life-Cycle Costs by Design Option for Electric Water Heaters

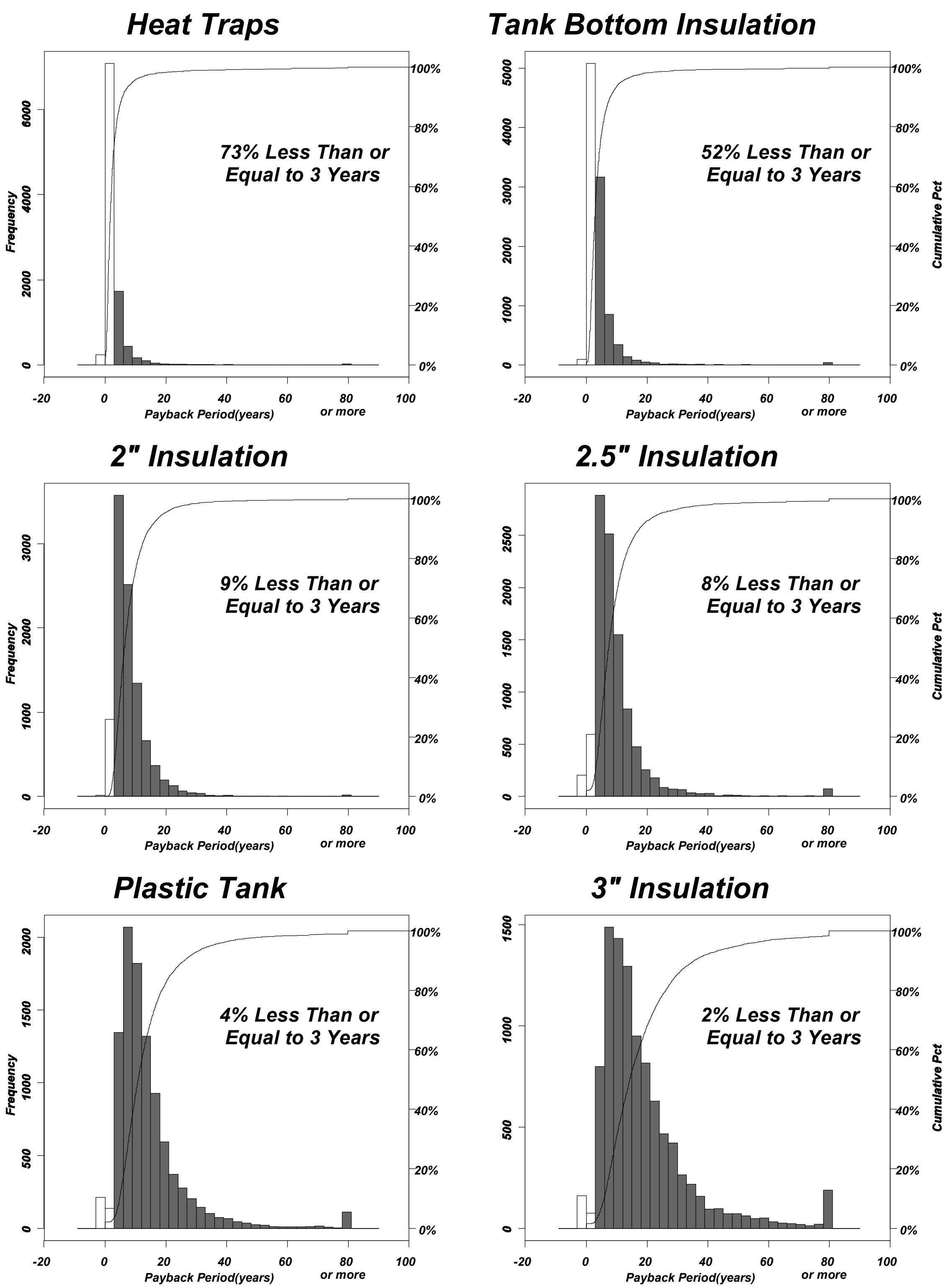

Figure 9.6.4 Payback Period by Design Option for Electric Water Heaters

9.6.4.2 Natural Gas Water Heaters

Table 9.6.4 lists the portion of the population that benefits, in terms of reduced life-cycle cost, from each design option. The average LCC savings and average payback are also shown.

Table 9.6.4 Life-Cycle Cost and Payback for Natural Gas Water Heaters

	Design Option	**Fraction of Population Benefitting** *%*	**Average LCC Savings** *$*	**Median Payback** *yrs*
1	Heat Traps	96	16	1.34
2	78% RE	75	5	3.40
3	78% RE, 2" Insulation	78	30	3.59
4	78% RE, 2.5" Insulation	64	11	5.12
5	80% RE, 2" Insulation	82	-15	2.88
6	80% RE, 2.5" Insulation	71	-34	4.21
7	80% RE, 3" Insulation	48	-95	6.92
8	Side Arm	18	-244	12.14

Figure 9.6.5 together with Table 9.6.5 present summary life-cycle cost information for natural gas water heaters. Each bar refers to a specific design option. The bar's height above the horizontal axis shows the percentage of households that have a life-cycle savings. Conversely, the portion of the bar below the horizontal axis shows the percentage of households that have a life-cycle net cost. As the design options increase energy efficiency and cost, the bars show a greater fraction of the population having net costs. The positive and negative portions of the bars are shaded to show three ranges: significant savings; significant costs; and no significant change. A change of less than two percent of the average baseline life-cycle cost is considered insignificant. The average baseline life-cycle cost is included as a reference point. For the households benefitting by a design option, the table shows the average and maximum savings for that fraction of the population and also the average and maximum costs for the corresponding disadvantaged fraction of the population.

Table 9.6.5 Percent of Sample Having Net Savings or Costs for Natural Gas Water Heaters

Population		**Heat Traps**	**78% RE**	**78% RE, 2-Inch Insul.**	**78% RE, 2.5-Inch Insul.**	**80% RE, 2-Inch Insul.**	**80% RE, 2.5-Inch Insul.**	**80% RE, 3-Inch Insul.**	**Side-Arm**
Significant Savings	% of sample	10%	22%	52%	40%	65%	52%	33%	14%
	Avg Savings	$41	$49	$73	$75	$87	$88	$88	$126
	Max Savings	$97	$156	$359	$349	$452	$459	$515	$700
Insignificant (a)	% of sample	90%	67%	36%	39%	23%	28%	25%	9%
Significant Cost	% of sample	0.0%	11%	12%	21%	12%	19%	41%	77%
	Avg Cost	-	$109	$92	$94	$603	$420	$304	$342
	Max Cost	$26	$246	$300	$385	$1,863	$1,897	$2,087	$2,365
Total (100%)	Avg Savings	$16	$5	$30	$11	-$15	-$34	-$95	-$244

(a) cost or savings < 2% of average baseline LCC [$31]

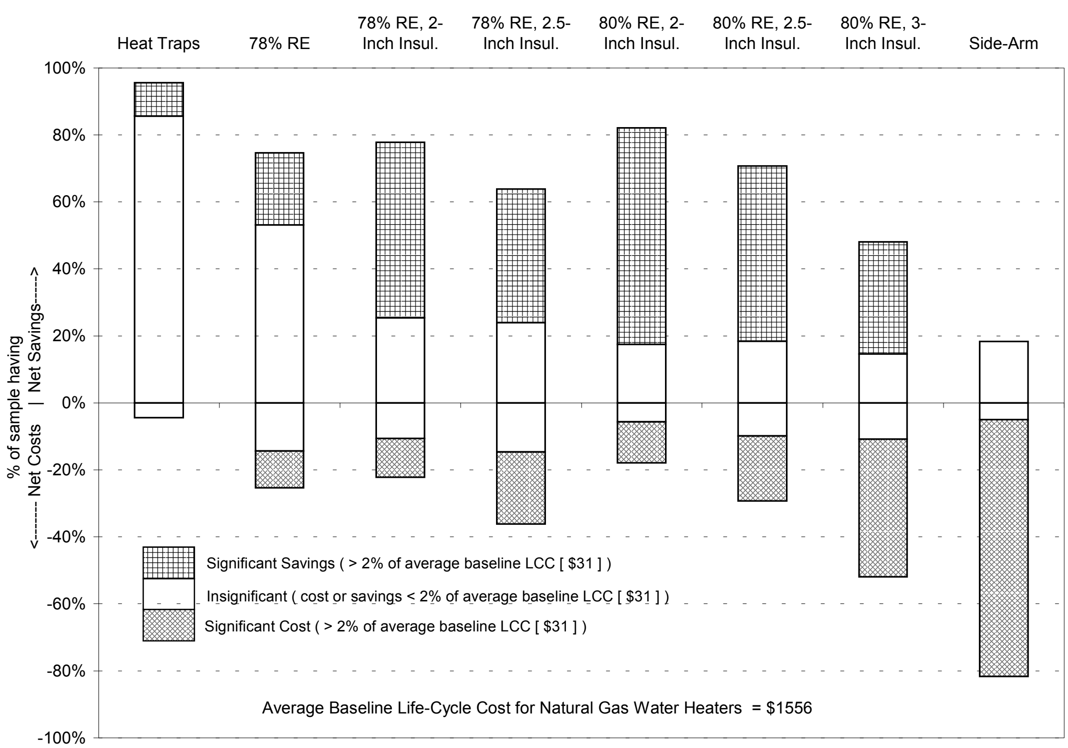

Figure 9.6.5 Percent of Sample Having Net Savings or Costs for Natural Gas Water Heaters

Figure 9.6.6 shows the cumulative frequency of differences in LCC by design option for natural gas water heaters. The percentages of the population that do and do not benefit are also shown on the graph. Figure 9.6.7 shows cumulative frequency of payback period by design option. The percent of population that would have a payback of less than or equal to three years is indicated.

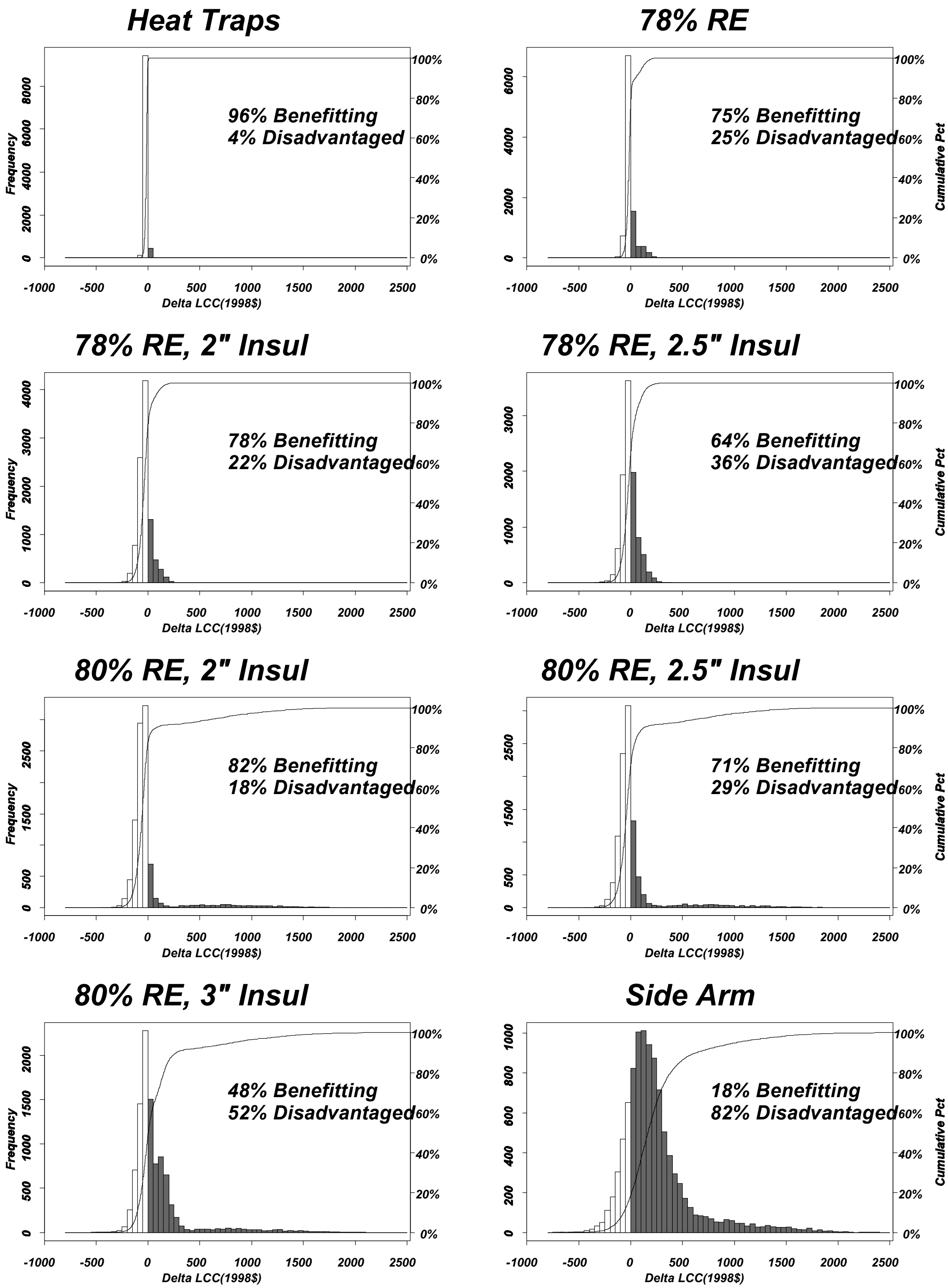

Figure 9.6.6 Difference in Life-Cycle Costs by Design Option for Natural Gas Water Heaters

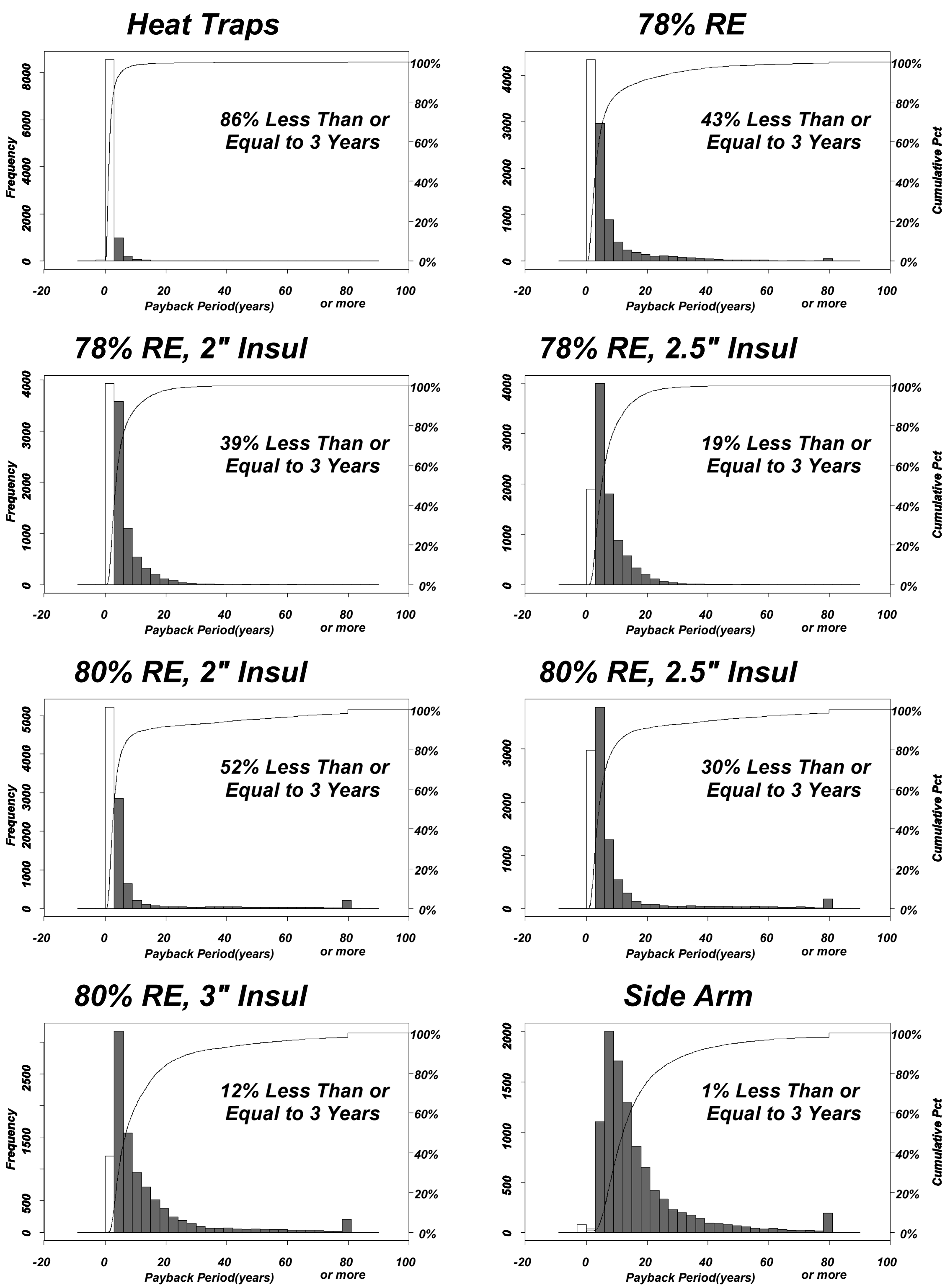

Figure 9.6.7 Payback Period by Design Option for Natural Gas Water Heaters

9.6.4.3 LPG Water Heaters

Table 9.6.6 lists the portion of the population that benefits, in terms of reduced life-cycle cost, from each design option for LPG water heaters. The average LCC savings and average payback are also shown.

Table 9.6.6 Life-Cycle Cost and Payback for LPG Water Heaters

	Design Option	Fraction of Population Benefitting *%*	Average LCC Savings *$*	Median Payback *yrs*
1	Heat Traps	98	34	1.03
2	78% RE	83	32	2.70
3	78% RE, 2" Insulation	89	97	2.82
4	78% RE, 2.5" Insulation	78	77	3.96
5	80% RE, 2" Insulation	88	62	2.28
6	80% RE, 2.5" Insulation	82	42	3.29
7	80% RE, 3" Insulation	62	-26	5.13
8	Side Arm	37	-122	8.33

Figure 9.6.8 together with Table 9.6.7 present summary life-cycle cost information for LPG water heaters. Each bar refers to a specific design option. The bar's height above the horizontal axis shows the percentage of households that have a life-cycle savings. Conversely, the portion of the bar below the horizontal axis shows the percentage of households that have a life-cycle net cost. As the design options increase energy efficiency and cost, the bars show a greater fraction of the population having net costs. The positive and negative portions of the bars are shaded to show three ranges: significant savings; significant costs; and no significant change. A change of less than two percent of the average baseline life-cycle cost is considered insignificant. The average baseline life-cycle cost is included as a reference point. For the households benefitting by a design option, the table shows the average and maximum savings for that fraction of the population and also the average and maximum costs for the corresponding disadvantaged fraction of the population.

Table 9.6.7 Percent of Sample Having Net Savings or Costs for LPG Water Heaters

Population		Heat Traps	78% RE	78% RE, 2-Inch Insul.	78% RE, 2.5-Inch Insul.	80% RE, 2-Inch Insul.	80% RE, 2.5-Inch Insul.	80% RE, 3-Inch Insul.	Side-Arm
Significant Savings	% of sample	22%	35%	69%	58%	78%	69%	48%	30%
	Avg Savings	$71	$91	$143	$150	$175	$178	$186	$312
	Max Savings	$326	$574	$1,242	$1,389	$1,750	$1,548	$2,071	$3,111
Insignificant (a)	% of sample	78%	56%	26%	32%	12%	19%	22%	12%
Significant Cost	% of sample	0.00%	9%	5%	11%	10%	12%	30%	57%
	Avg Cost	-	$116	$104	$112	$778	$671	$395	$378
	Max Cost	$35	$233	$230	$335	$1,840	$1,880	$2,060	$2,202
Total (100%)	Avg Savings	$34	$32	$97	$77	$62	$42	-$26	-$122

(a) cost or savings < 2% of average baseline LCC [$47]

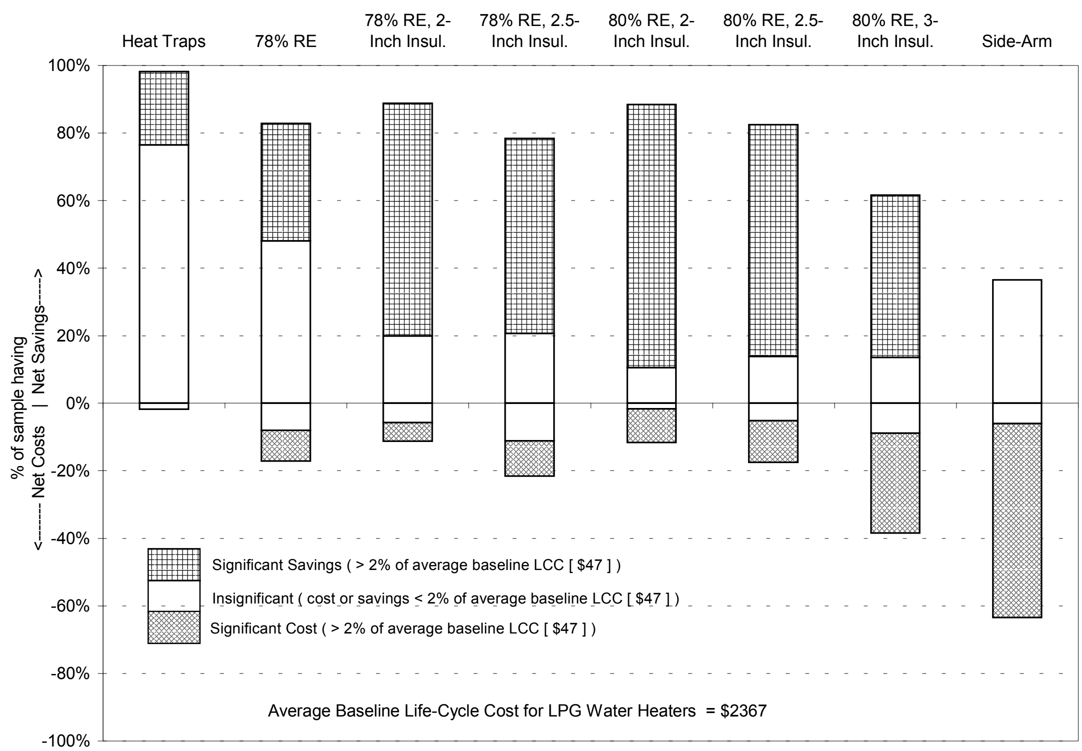

Figure 9.6.8 Percent of Sample Having Net Savings or Costs for LPG Water Heaters

Figure 9.6.9 shows the cumulative frequency of differences in LCC by design option for LPG water heaters. The percentages of the population that do and do not benefit are also shown on the graph. Figure 9.6.10 shows cumulative frequency of payback period by design option. The percent of population that would have a payback of less than or equal to three years is indicated.

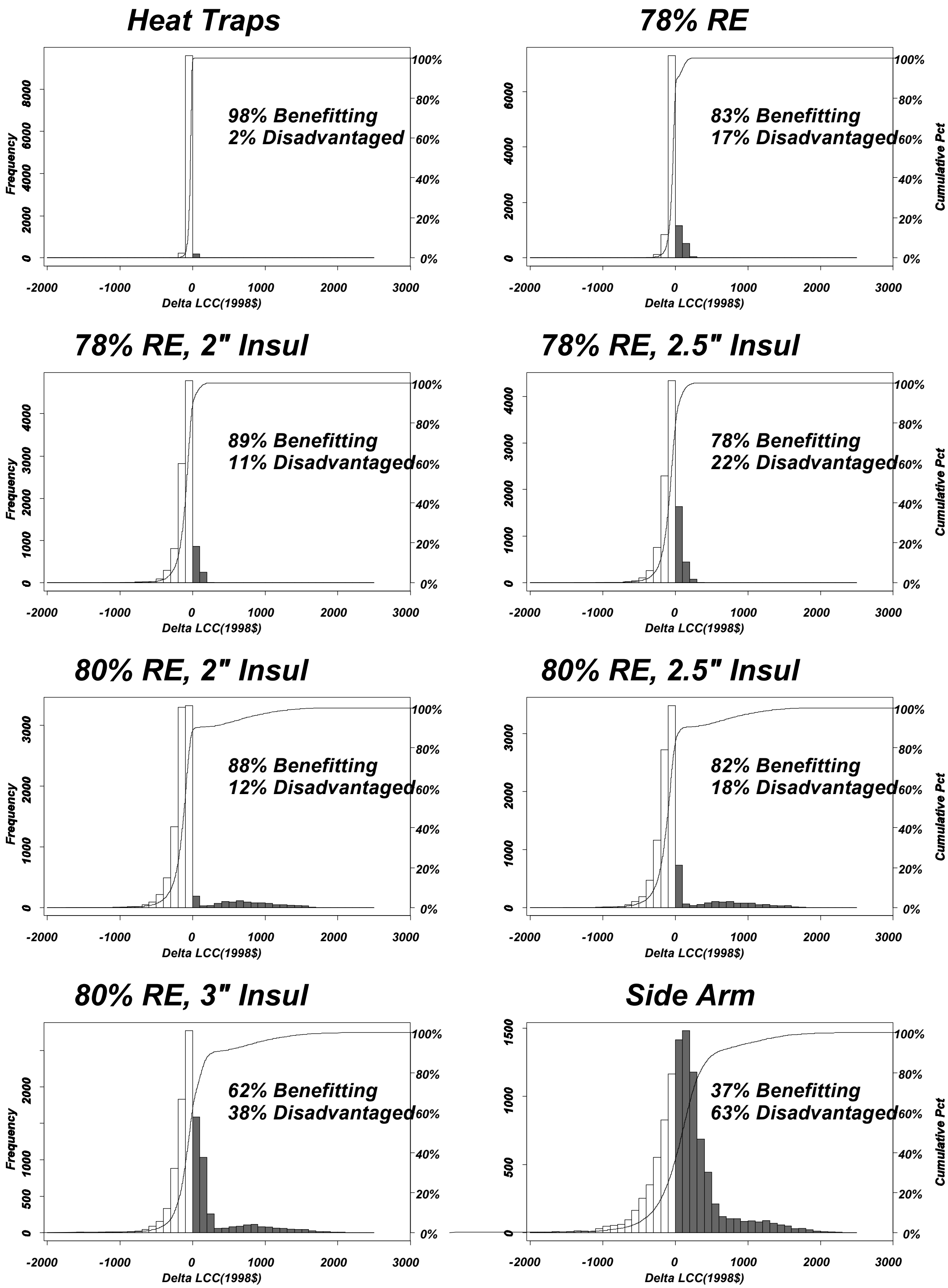

Figure 9.6.9 Difference in Life-Cycle Costs by Design Option for LPG Water Heaters

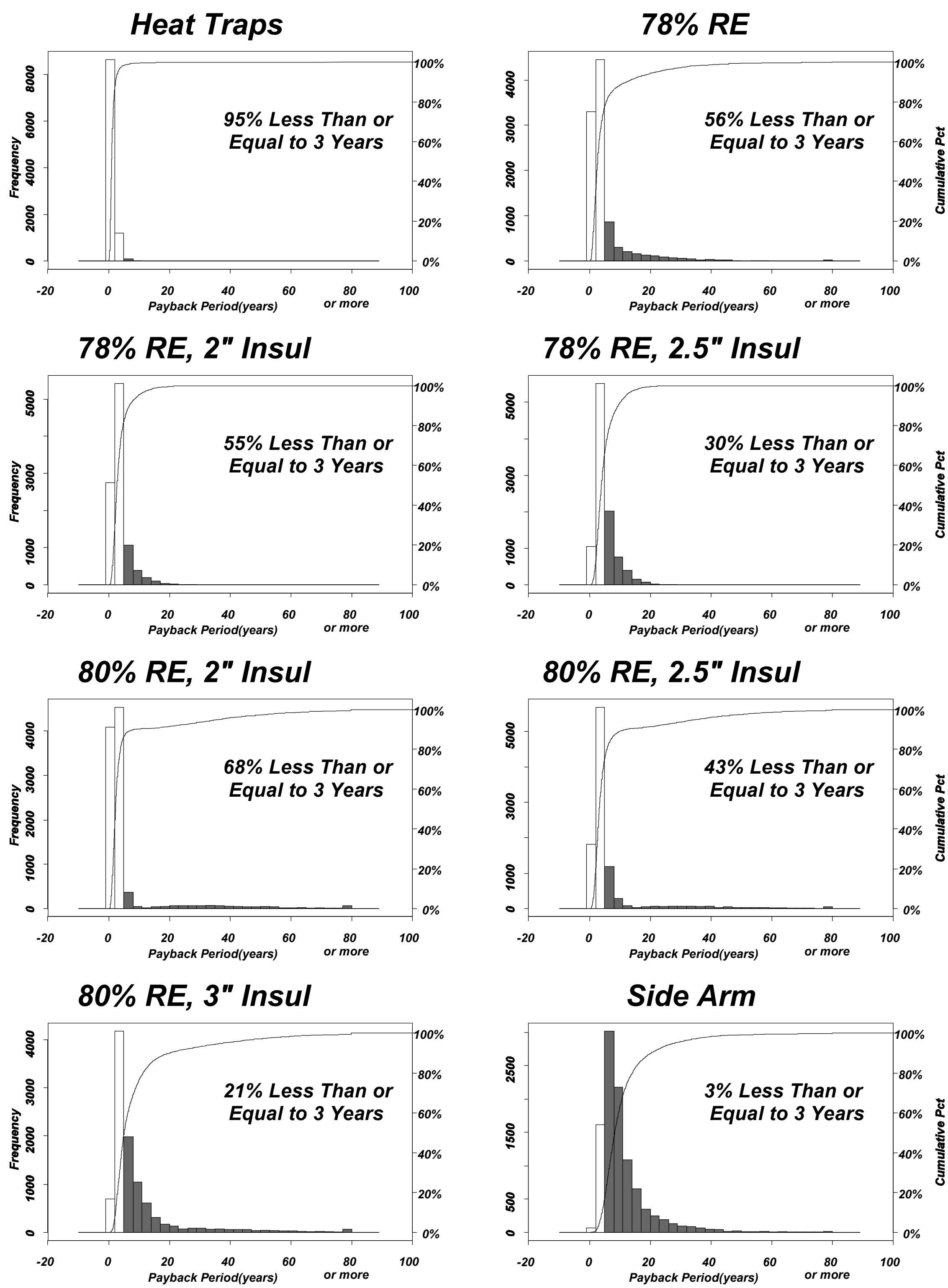

Figure 9.6.10 Payback Period by Design Option for LPG Water Heaters

9.6.4.4 Oil-Fired Water Heaters

Table 9.6.8 lists the portion of the population that benefits, in terms of reduced life-cycle cost from each design option for oil-fired water heaters. The average LCC savings and average payback are also shown.

Table 9.6.8 Life-Cycle Cost and Payback for Oil-Fired Water Heaters

Design Option		Fraction of Population Benefitting *(%)*	Average LCC Savings *($)*	Median Payback *(yrs)*
1	Heat Traps	25	-15	8.2
2	2" Insulation	7	-46	12.3
3	2.5" Insulation	3	-72	14.2
4	3" Insulation	1	-103	16.5
5	78% RE	0.1	-209	19.9
6	Interrupted Ignition	0.4	-242	19.4
7	Increased HX Area	0.1	-459	24.6

Figure 9.6.11 together with Table 9.6.9 present summary life-cycle cost information for oil-fired water heaters. Each bar refers to a specific design option. The bar's height above the horizontal axis shows the percentage of households that have a life-cycle savings. Conversely, the portion of the bar below the horizontal axis shows the percentage of households that have a life-cycle net cost. As the design options increase energy efficiency and cost, the bars show a greater fraction of the population having net costs. The positive and negative portions of the bars are shaded to show three ranges: significant savings; significant costs; and no significant change. A change of less than two percent of the average baseline life-cycle cost is considered insignificant. For all but the first two or three design options, the majority of households with oil-fired water heaters face a significant cost. The average baseline life-cycle cost is included as a reference point. For the households benefitting by a design option, the table shows the average and maximum savings for that fraction of the population and also the average and maximum costs for the corresponding disadvantaged fraction of the population.

Table 9.6.9 Percent of Sample Having Net Savings or Costs for Oil-Fired Water Heaters

Population		Heat Traps	2-Inch Insul.	2.5-Inch Insul.	3-Inch Insul.	78% RE	Inter. Ignition	Incr. HX Area
Significant Savings	% of sample	0.1%	0.3%	0.1%	0.04%	0.03%	0.1%	0.1%
	Avg Savings	$66	$72	$75	$82	$201	$146	$251
	Max Savings	$100	$105	$113	$100	$253	$440	$478
Insignificant[1]	% of sample	91%	62%	33%	13%	1%	1%	0%
Significant Cost	% of sample	8.80%	38%	67%	87%	99%	99%	100%
	Avg Cost	$73	$73	$93	$114	$211	$245	$460
	Max Cost	$159	$159	$242	$281	$442	$504	$919
Total (100%)	Avg Savings	-$15	-$46	-$72	-$103	-$209	-$242	-$459

[1] Cost or savings < 2% of average baseline LCC [$56]

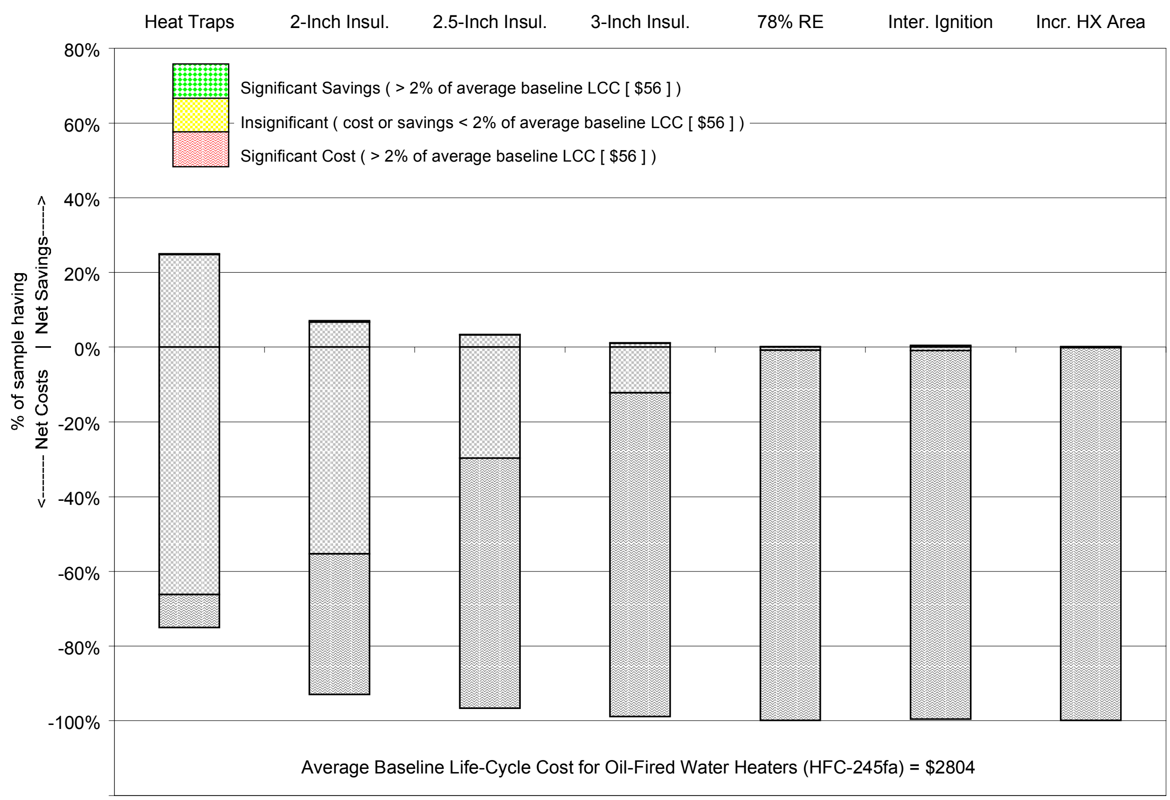

Figure 9.6.11 Percent of Sample Having Net Savings or Costs for Oil-Fired Water Heaters

Figure 9.6.12 shows the cumulative frequency of differences in LCC by design option for oil-fired water heaters. The percentages of the population that do and do not benefit are also shown on the graph. Figure 9.6.13 shows cumulative frequency of payback period by design option for oil-fired water heaters. The percent of population that would have a payback of less than or equal to three years is indicated.

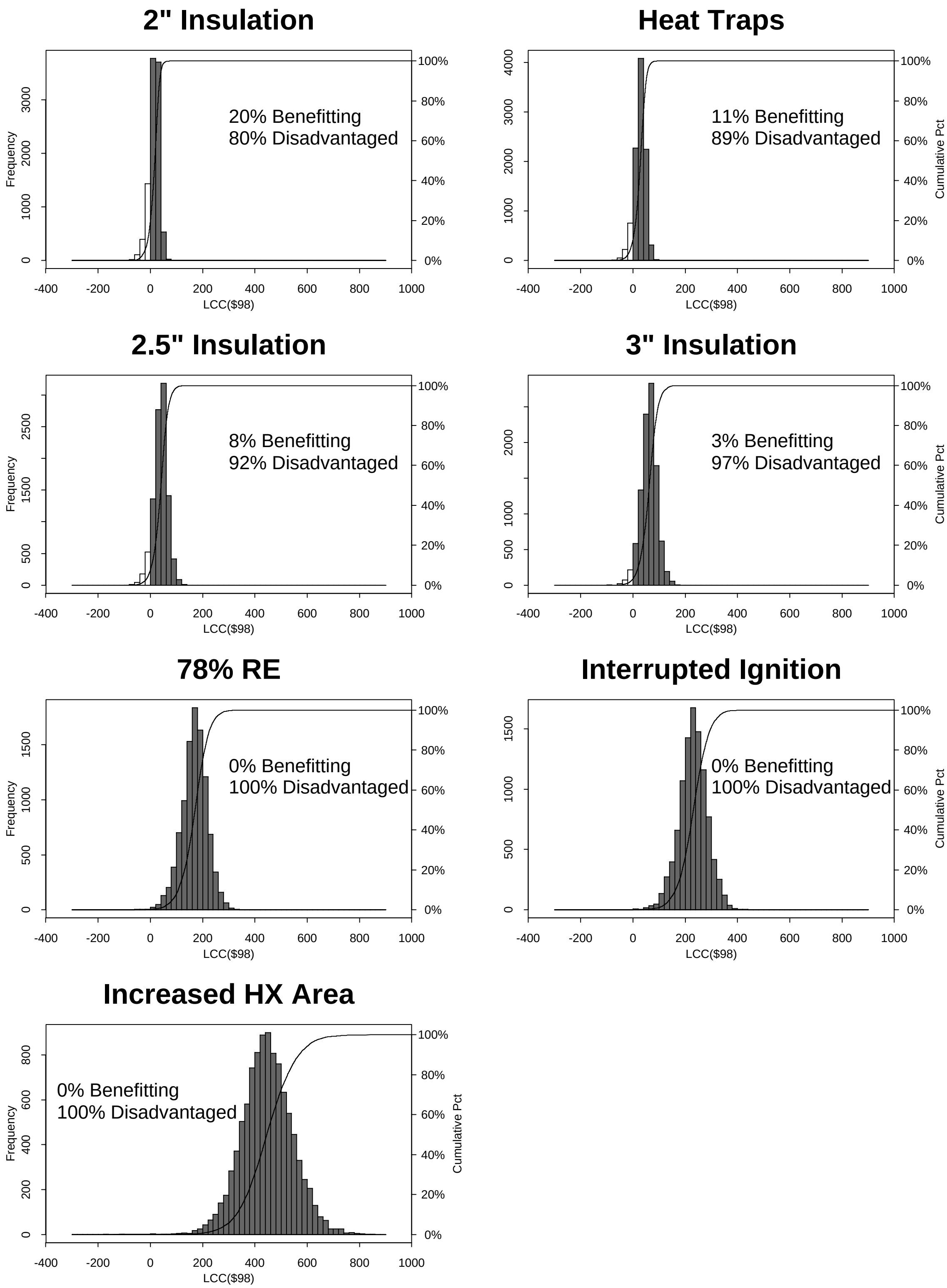

Figure 9.6.12 Difference in Life-Cycle Costs by Design Option for Oil-Fired Water Heaters

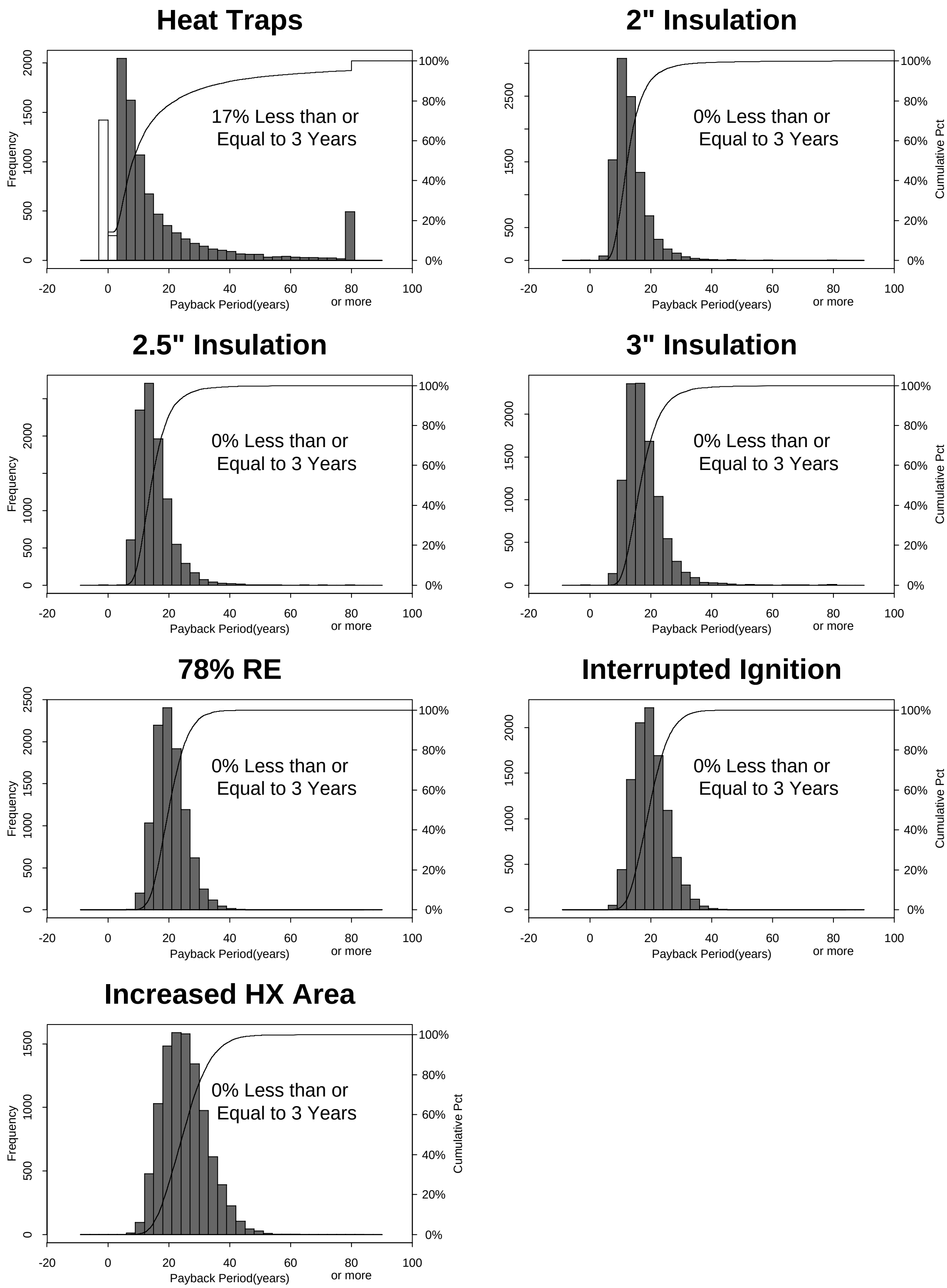

Figure 9.6.13 Payback Period by Design Option for Oil-Fired Water Heaters

9.6.5 Importance Analysis

Figures 9.6.14 through 9.6.17 show the results of the importance analysis for LCC for electric, natural gas, LPG, and oil water heaters for Trial Standard Level 3. Figures 9.6.18, 9.6.19, and 9.6.20 show the input importance analysis for payback period for electric, natural gas, and LPG water heaters for Trial Standard Level 3. Because the oil water heater design option which corresponds to Level 3 is the baseline water heater, it is not possible to calculate the payback for this level, since payback is defined by differences in installed and operating costs between the design option and the baseline water heater. Variables are ordered with maximum correlation coefficients values (positive or negative) on top and minimum coefficients on the bottom. The input of most importance to the LCC is annual operating cost, followed by discount rate for electric water heaters, and lifetime for natural gas, LPG, and oil water heaters.

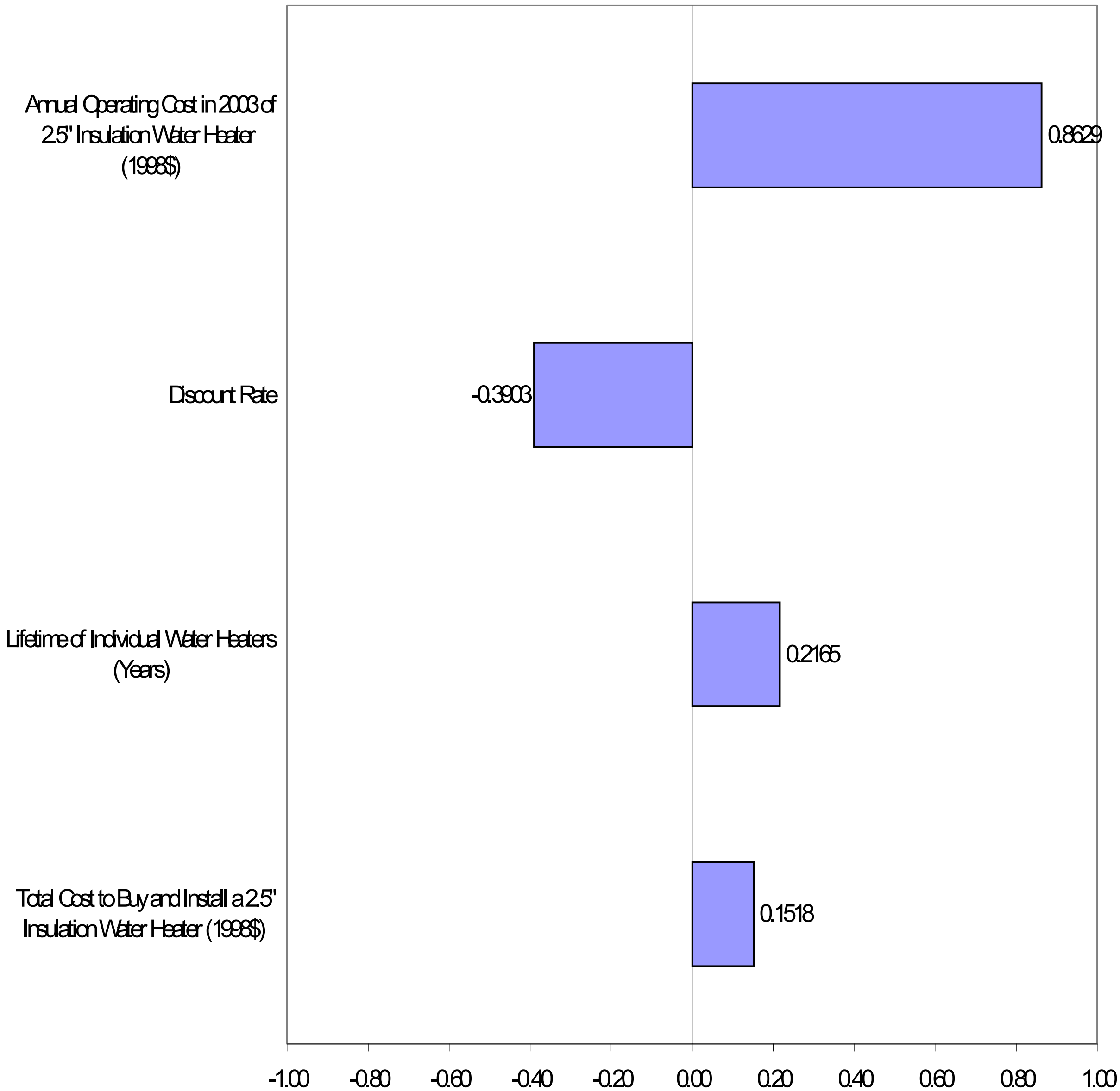

Figure 9.6.14 Importance of Input Variables to the Life-Cycle Cost for 2.5" Insulation on Electric Water Heaters

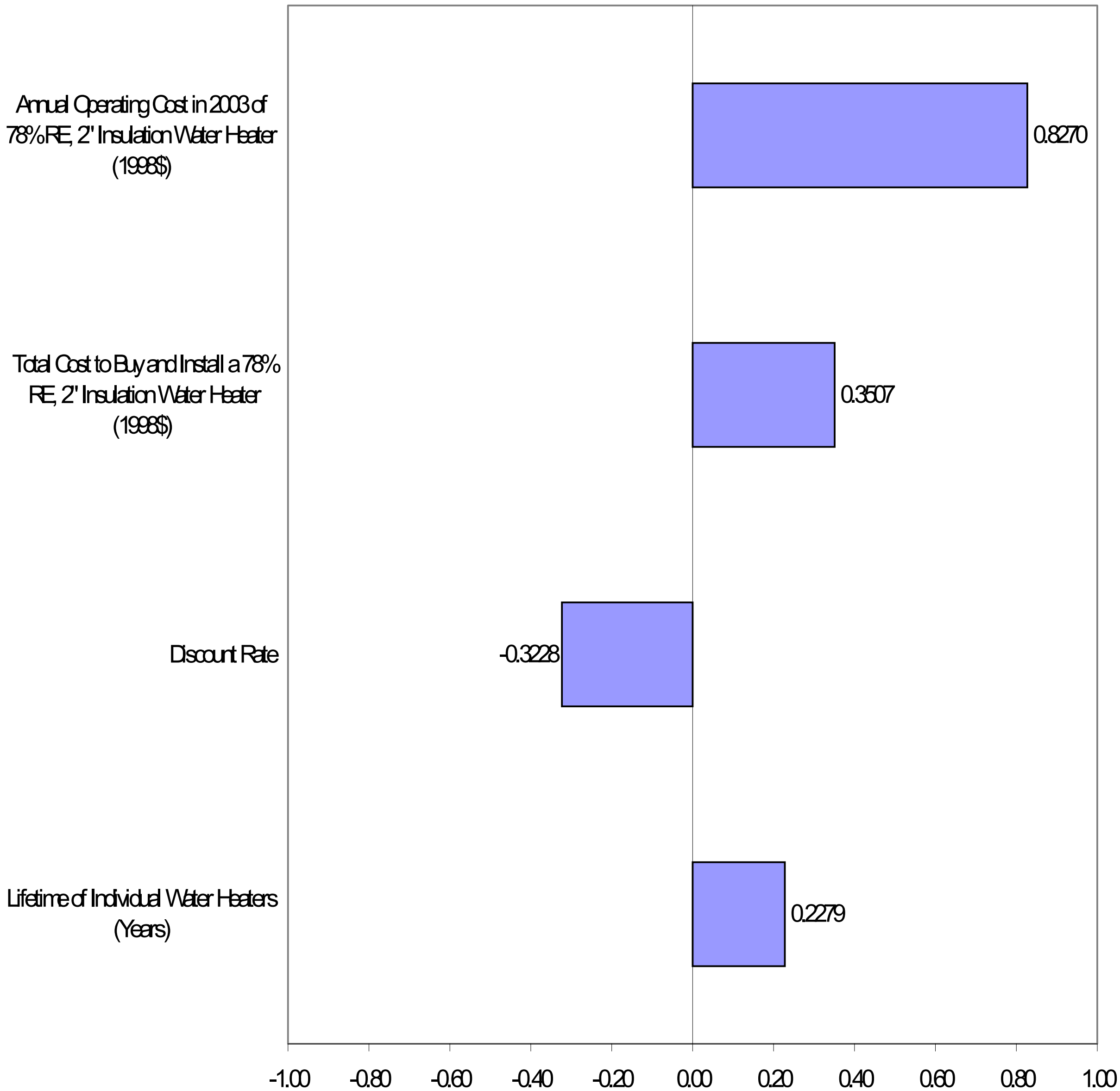

Figure 9.6.15 Importance of Input Variables to the Life-Cycle Cost for 78% RE 2" Insulation on Natural Gas Water Heaters

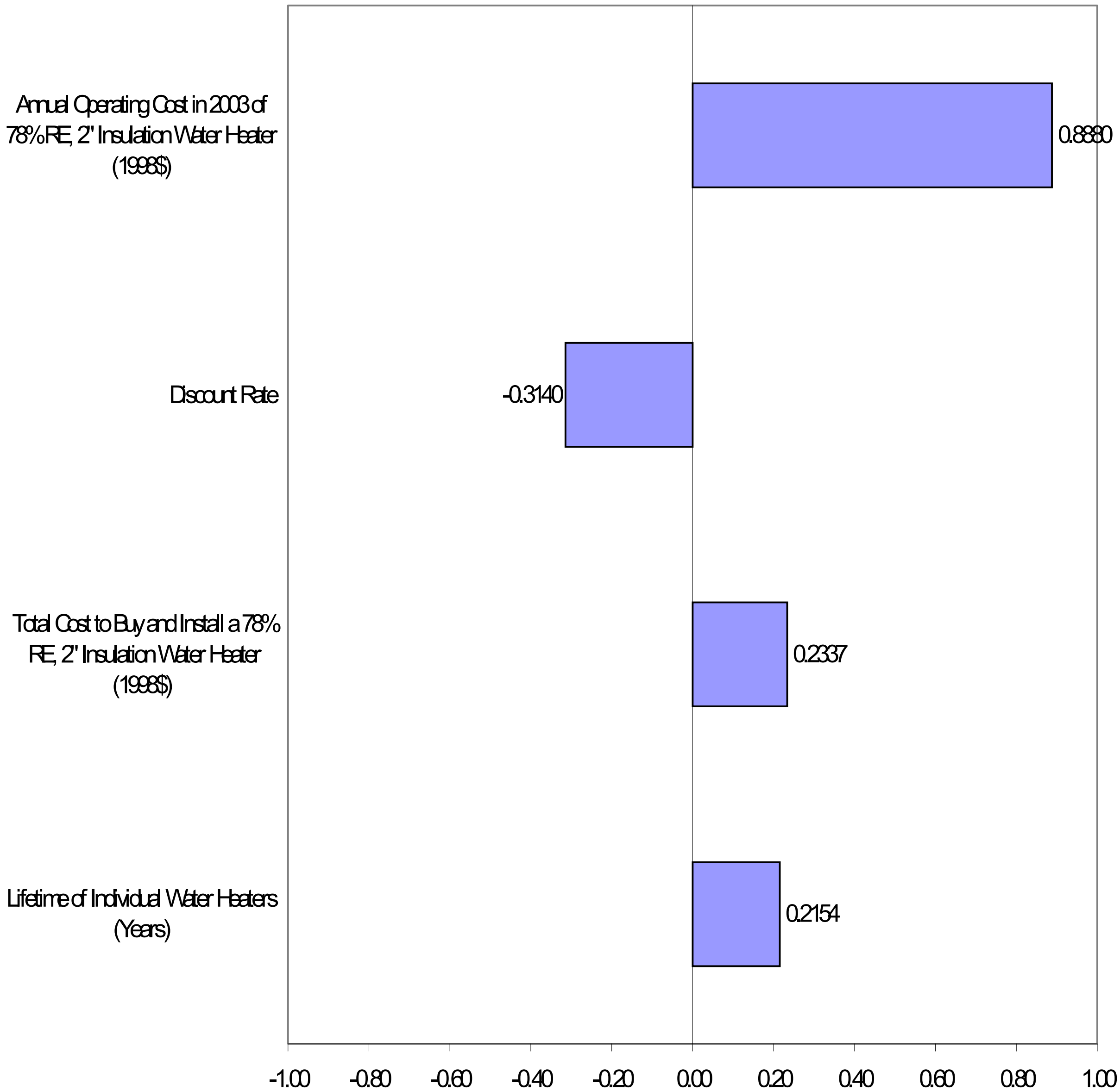

Figure 9.6.16 Importance of Input Variables to the Life-Cycle Cost for 78% RE 2" Insulation on LPG Water Heaters

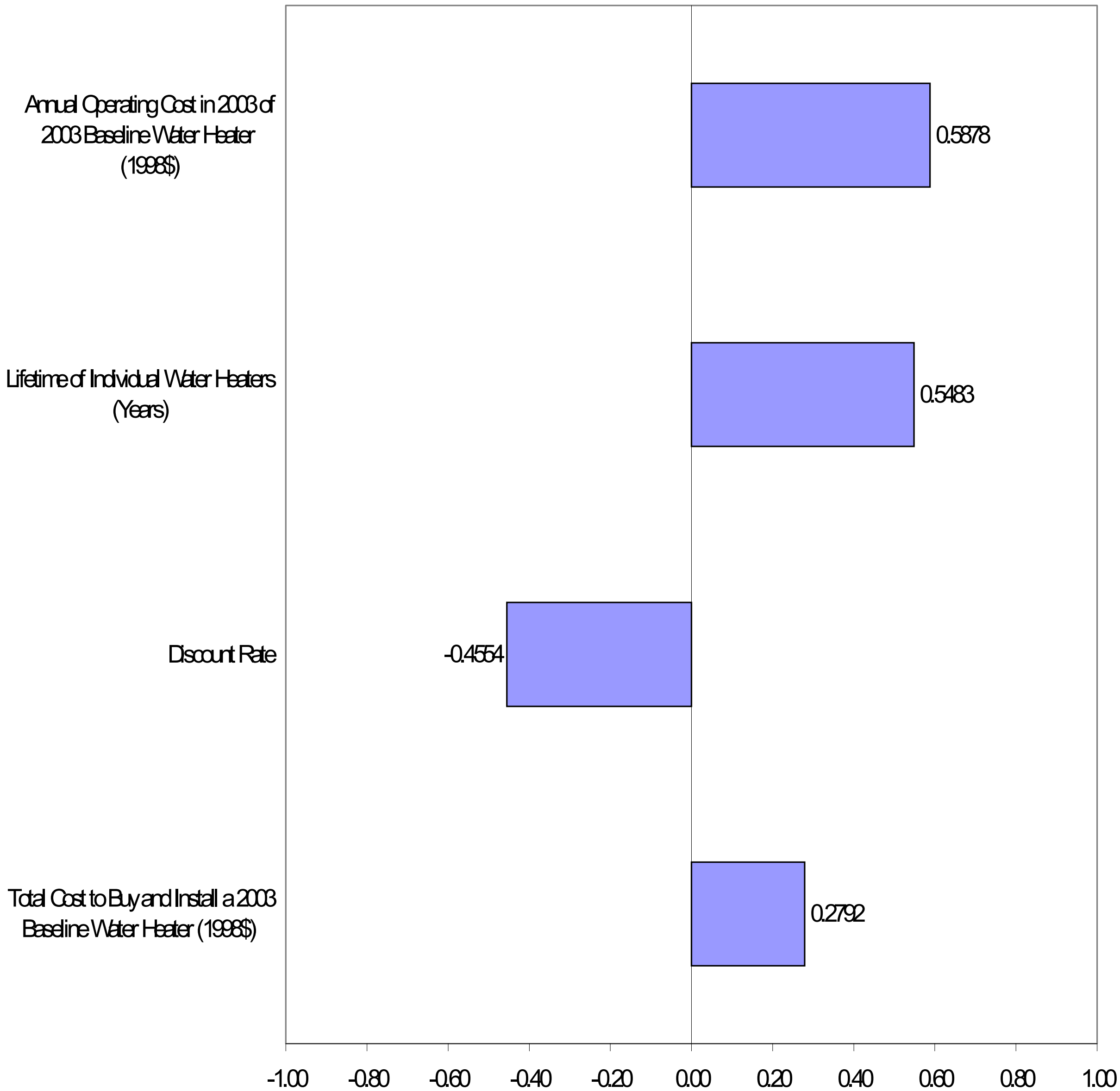

Figure 9.6.17 Importance of Input Variables to the Life-Cycle Cost for 2003 Baseline Oil-Fired Water Heaters

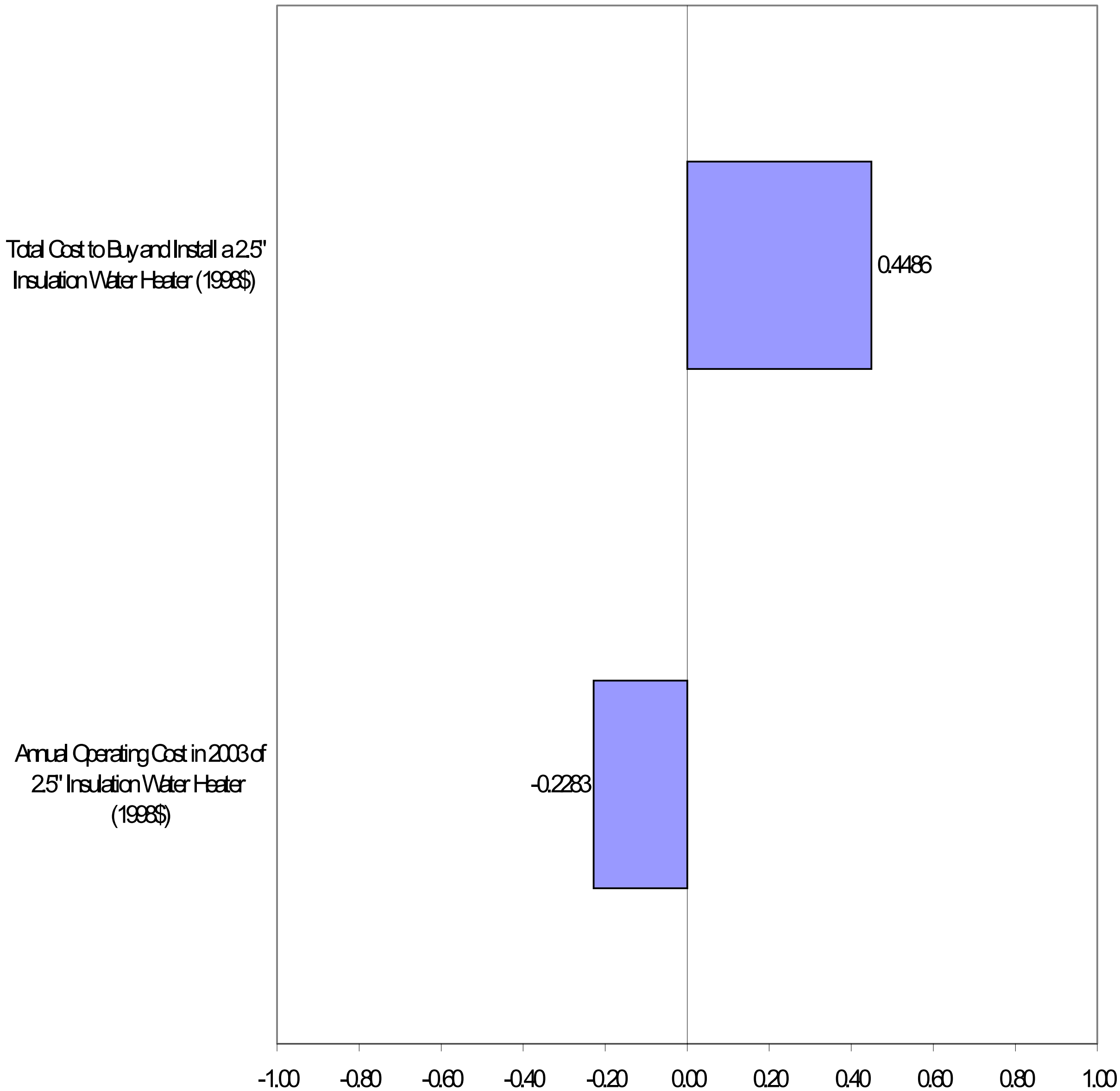

Figure 9.6.18 Importance of Input Variables to the Payback Period for 2.5" Insulation on Electric Water Heaters

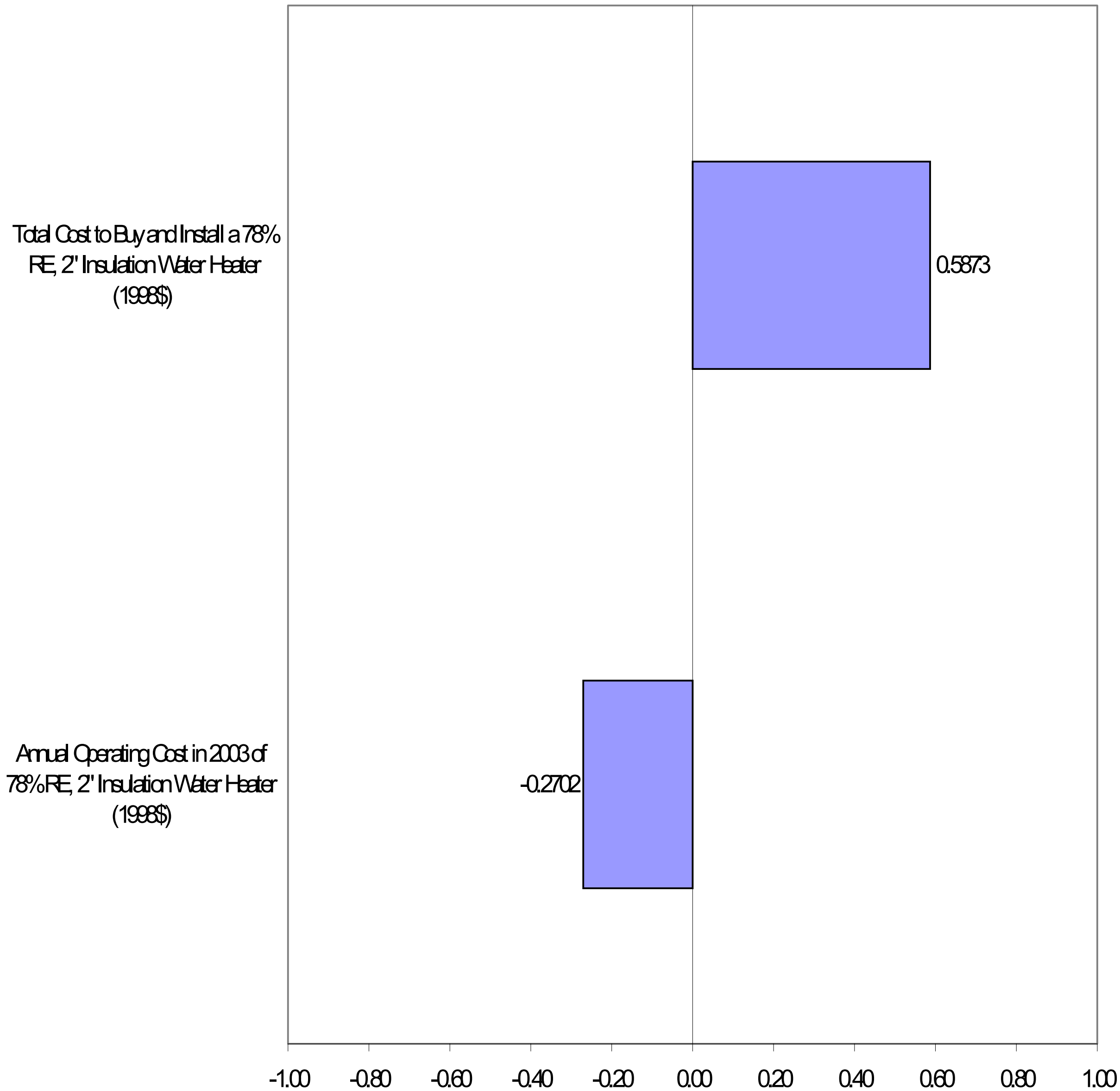

Figure 9.6.19 Importance of Input Variables to the Payback Period for 78% RE 2" Insulation on Natural Gas Water Heaters

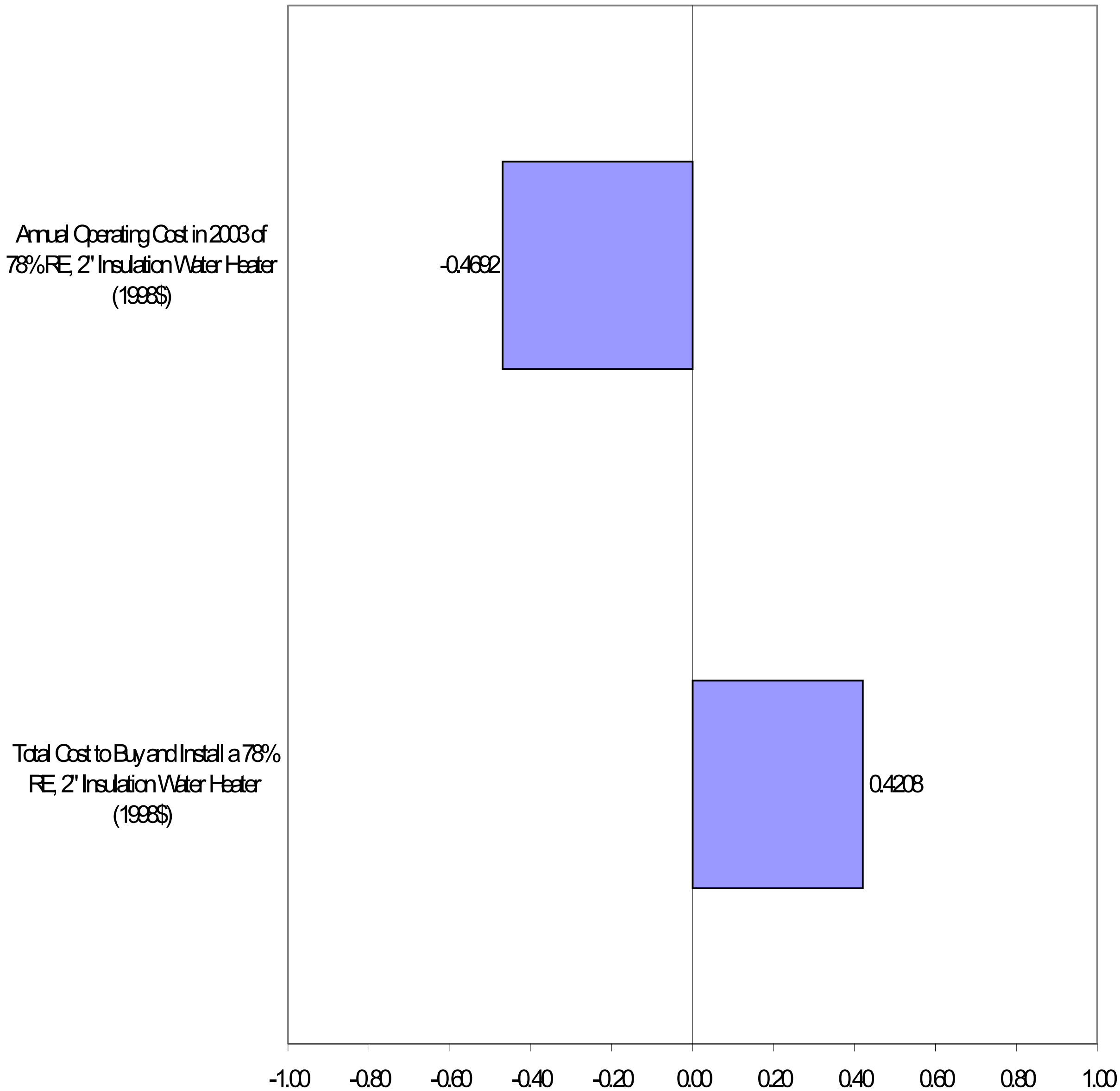

Figure 9.6.20 Importance of Input Variables to the Payback Period for 78% RE 2" Insulation on LPG Water Heaters

9.7 TRIAL STANDARD LEVELS

The Engineering and Life-Cycle Cost Analyses are done for all design options separately for each fuel. The subsequent analyses (e.g., Consumer Sub-Group, Shipments) are done using trial standard levels and all fuels are considered together. Trial standard levels consist of one design option from each fuel type. Tables 9.7.1 through 9.7.4 show the assignment of design options to trial standard levels for electric, natural gas, LPG, and oil-fired water heaters, respectively.

Table 9.7.1 Trial Standard Levels for Design Options: Electric Water Heaters

Trial Standard Level	Design Option	Short Name	Full Description
	00	Existing Baseline	Baseline (141b)
	0	2003 Baseline	Baseline (245fa)
	1	Heat Traps	2003 Baseline + Heat Traps
1	2	Tank Bottom Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation
2	3	2" Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation + 2" Insulation
3	4	2.5" Insulation	2003 Baseline + Heat Traps + Tank Bottom Insulation + 2.5" Insulation
	5	Plastic Tank	2003 Baseline + Heat Traps + 2.5" Insulation + Plastic Tank
4	6	3" Insulation	2003 Baseline + Heat Traps + 3" Insulation + Plastic Tank

Table 9.7.2 Trial Standard Levels for Design Options: Natural Gas Water Heaters

Trial Standard Level	Design Option	Short Name	Full Description
	00	Existing Baseline	Baseline (141b)
	0	2003 Baseline	Baseline (245fa)
	1	Heat Traps	2003 Baseline + Heat Traps
	2	78% RE	2003 Baseline + Heat Traps + Improved Flue Baffles (78% RE)
1, 3	3	78% RE, 2" Insul	2003 Baseline + Heat Traps + Improved Flue Baffles (78% RE) + 2" Insulation
2	4	78% RE, 2.5" Insul	2003 Baseline + Heat Traps + Improved Flue Baffles (78% RE) + 2.5" Insulation
	5	80% RE, 2" Insul	2003 Baseline + Heat Traps + Improved Flue Baffles (80% RE) + 2" Insulation
	6	80% RE, 2.5" Insul	2003 Baseline + Heat Traps + Improved Flue Baffles (80% RE) + 2.5" Insulation
	7	80% RE, 3" Insul	2003 Baseline + Heat Traps + Improved Flue Baffles (80% RE) + 3" Insulation
4	8	Side Arm	2003 Baseline + Heat Traps + Improved Flue Baffles (80% RE) + 3" Insulation + Side Arm + Electronic Ignition + Plastic Tank

RE= Recovery Efficiency

Table 9.7.3 Trial Standard Levels for Design Options: LPG Water Heaters

Trial Standard Level	Design Option	Short Name	Full Description
	00	Existing Baseline	Baseline (141b)
	0	2003 Baseline	Baseline (245fa)
	1	Heat Traps	2003 Baseline + Heat Traps
	2	78% RE	2003 Baseline + Heat Traps + Improved Flue Baffles (78% RE)
1, 3	3	78% RE, 2" Insul	2003 Baseline + Heat Traps + Improved Flue Baffles (78% RE) + 2" Insulation
2	4	78% RE, 2.5" Insul	2003 Baseline + Heat Traps + Improved Flue Baffles (78% RE) + 2.5" Insulation
	5	80% RE, 2" Insul	2003 Baseline + Heat Traps + Improved Flue Baffles (80% RE) + 2" Insulation
	6	80% RE, 2.5" Insul	2003 Baseline + Heat Traps + Improved Flue Baffles (80% RE) + 2.5" Insulation
	7	80% RE, 3" Insul	2003 Baseline + Heat Traps + Improved Flue Baffles (80% RE) + 3" Insulation
4	8	Side Arm	2003 Baseline + Heat Traps + Improved Flue Baffles (80% RE) + 3" Insulation + Side Arm + Electronic Ignition + Plastic Tank

RE= Recovery Efficiency

Table 9.7.4 Trial Standard Levels for Design Options: Oil-Fired Water Heaters

Trial Standard Level	Design Option	Short Name	Full Description
	00	Existing Baseline	Baseline (141b)
3	0	2003 Baseline	Baseline (245fa)
1, 2	1	Heat Traps	2003 Baseline + Heat Traps
	2	2" Insulation	2003 Baseline + Heat Traps + 2" Insulation
	3	2.5" Insulation	2003 Baseline + Heat Traps + 2.5" Insulation
	4	3" Insulation	2003 Baseline + Heat Traps + 3" Insulation
	5	78% RE	2003 Baseline + Heat Traps + 3" Insulation + Improved Flue Baffles (78% RE)
	6	Interrupted Ignition	2003 Baseline + Heat Traps + 3" Insulation + Improved Flue Baffles (78% RE) + Interrupted Ignition
4	7	Increased HX Area	2003 Baseline + Heat Traps + 3" Insulation + Interrupted Ignition + Increased Heat Exchanger Area (82% RE)

RE= Recovery Efficiency

9.8 STATISTICAL SIGNIFICANCE

9.8.1 Background

We tested the validity of our LCC calculation methodology by conducting a statistical analysis of the LCC results. We wanted to verify that the differences between design options were true differences and not the result of sampling variation. Results for 10,000 simulations of life-cycle and energy costs under different design options were examined to determine which design option(s) generated lower life-cycle and/or energy costs.

Since each simulation consists of the same input variables (representing a hypothetical household) measured at both a baseline and different design options, the variables used in the analysis were calculated by subtracting the appropriate baseline value from the value obtained under one of the proposed design options. This achieves two very important goals. First, since each household serves as its own control, the precision of statistical tests is dramatically increased, allowing techniques such as t-tests and analysis of variance (ANOVA) to effectively detect differences undetected from samples not having built-in controls. Secondly, using differences instead of the original values eliminates possible problems due to correlation among the simulations. We considered two variables: Delta LCC, representing the difference in LCC value between a design option and its baseline value, and Delta Q, representing the difference in energy consumption between a design option and its baseline value.

9.8.2 Analytic Results

With data representing differences from a baseline value, there are usually two main questions of interest. First, since a difference of zero represents no change, it is of interest to determine if the mean difference observed under a particular design option is different from zero. The appropriate statistical test for this purpose is a one-sample t-test. The results of one-sample t-tests for both the Delta LCC values and the Delta Q values are summarized in Tables 9.8.1 through 9.8.4. We have shown the results for electric and gas-fired water heaters.

The extremely low probability levels (Pr(mean = 0)) seen in the tables are an indication that the means being studied are significantly different from zero. Thus, for each of the design options, the mean value reported can be considered to be different from zero, and electric water heater design options 1, 2, 3, and 4 result in lower-than-baseline LCC values, while design options 5 and 6 result in higher-than-baseline LCC values. Gas-fired water heater design options 1, 2, 3, and 4 result in lower-than-baseline LCC values, while design options 5, 6, 7, and 8 result in higher-than-baseline LCC values. For the energy consumption variables, it is clear that each of the electric water heater design options shows lower energy consumption, and, as we proceed through the design options going from 1 to 6, the reduction in consumption increases, with design option 6 showing the largest reduction. However, for gas-fired water heaters, each design option shows an increased energy consumption with design option 8 showing the largest increase.

Table 9.8.1 Sample t-test Results for Electric Delta LCC

Delta LCC					
Design Option	**Lower 95% Confidence Interval** ***$***	**Average** ***$***	**Upper 95% Confidence Interval** ***$***	**t-value** ***$***	**Pr (average = 0)**
1	-31.14	-30.56	-29.98	-102.84	< .0001
2	-36.57	-35.85	-35.13	-97.38	< .0001
3	-32.93	-31.69	-30.46	-50.27	< .0001
4	-24.62	-22.64	-20.67	-22.51	< .0001
5	18.39	20.55	22.71	18.64	< .0001
6	79.25	82.12	85.00	55.94	< .0001

Table 9.8.2 Sample t-test Results for Electric Delta Q

Delta Q					
Design Option	**Lower 95 % Confidence Interval** ***(Btu/day)***	**Average** ***(Btu/day)***	**Upper 95 % Confidence Interval** ***(Btu/day)***	**t-value** ***(Btu/day)***	**Pr (average = 0)**
1	-544	-539	-533	-176	<.0001
2	-735	-728	-721	-207	<.0001
3	-1336	-1325	-1315	-253	<.0001
4	-1777	-1760	-1744	-205	<.0001
5	-1861	-1843	-1825	-200	<.0001
6	-2133	-2114	-2095	-215	< .0001

Table 9.8.3 Sample t-test Results for Gas Delta LCC

Delta Q					
Design Option	**Lower 95 % Confidence Interval** *(Btu/day)*	**Average** *(Btu/day)*	**Upper 95 % Confidence Interval** *(Btu/day)*	**t-value** *(Btu/day)*	**Pr (average = 0)**
1	-15.88	-15.65	-15.41	-132.47	<.0001
2	-6.36	-5.43	-4.49	-11.35	<.0001
3	-31.66	-30.44	-29.21	-48.70	<.0001
4	-12.88	-11.45	-10.02	-15.69	<.0001
5	9.62	15.10	20.59	5.40	<.0001
6	28.29	33.84	39.38	11.96	< .0001
7	88.69	94.66	100.63	31.09	< .0001
8	237.24	244.17	251.10	69.09	< .0001

Table 9.8.4 Sample t-test Results for Gas Delta Q

Delta Q					
Design Option	**Lower 95 % Confidence Interval** *(Btu/day)*	**Average** *(Btu/day)*	**Upper 95 % Confidence Interval** *(Btu/day)*	**t-value** *(Btu/day)*	**Pr (average = 0)**
1	1308	1320	1331	225	<.0001
2	2436	2455	2475	243	<.0001
3	5962	5996	6029	352	<.0001
4	6645	6683	6720	352	<.0001
5	7380	7421	7464	347	<.0001
6	8068	8114	8159	350	< .0001
7	8517	8565	8612	352	< .0001
8	17733	17817	17900	419	< .0001

Having established that the changes in LCC and energy consumption values are actually different from zero, the other statistical question of interest has to do with comparisons among the different design options. For example, Table 9.8.1 indicates that the average difference from baseline

LCC values for design options 2 and 3 are -35.85 and -31.69, respectively. Having established that both of these values are significantly different from zero, it is of interest to test to see if these two mean values differ from each other. The appropriate statistical technique to test questions of this type is ANOVA, followed by a suitable multiple comparison procedure. Tables 9.8.5 and 9.8.6 present the results of these analyses for the Delta LCC and Delta Q values, respectively.

The very low probability values (Pr > F) in Tables 9.8.3 and 9.8.4 indicate that there are dramatic differences among the means of both LCC and energy consumption under the six electric water heater design options and eight gas-fired water heater design options. The multiple comparison test for electric delta LCC showed that the mean of each design option was significantly different from all the others, except for design options 1 and 3 which were not significantly different. The multiple comparison test for electric delta Q showed that the mean of each design option was significantly different from all of the other design options.

Table 9.8.5 Analysis of Variance for Electric Delta LCC

Source	df	Sum of Squares	Mean Square	F-value	Pr > F
Design Option	5	108487177	216978435	2601.32	< 0.0001
Residuals	59994	500406166	8341		
Total	59999	608893343			

Table 9.8.6 Analysis of Variance for Electric Delta Q

Source	df	Sum of Squares	Mean Square	F-value	Pr > F
Design Option	5	20332616649	4066523330	8034.00	< 0.0001
Residuals	59994	30366828258	506164		
Total	59999	50699444907			

The multiple comparison test for gas delta LCC (Table 9.8.7) showed that the means for design options 1, 2, and 4 were not significantly different, but that the means for the other design options were significantly different from 1, 2, and 4 as well as from all the other design options. The multiple comparison test for gas delta Q (Table 9.8.8) showed that the means for all the design options were significantly different from each other.

Table 9.8.7 Analysis of Variance for Gas Delta LCC

Source	df	Sum of Squares	Mean Square	F-value	Pr > F
Design Option	7	580969548.81	82995649.83	1712.95	< 0.0001
Residuals	79992	3875761505.45	48451.86		
Total	79999	4456731054.25			

Table 9.8.8 Analysis of Variance for Gas Delta Q

Source	df	Sum of Squares	Mean Square	F-value	Pr > F
Design Option	7	1.741903E+12	2.488433E+11	47617.56	< 0.0001
Residuals	79992	4.180279E+11	5.225871E+06		
Total	79999	2.159931E+12			

9.8.3 Conclusion

When the simulation results are viewed as paired observations between a baseline and a proposed design option (representing different design options), each of the design options produces changes in LCC and energy consumption values which are significantly different from zero. LCC values decreased for four of the electric and gas design options, and increased for the remaining. Energy consumption values decreased for all electric design options, with higher-numbered design options demonstrating increased reductions in consumption.

REFERENCES

1. U.S. Department of Energy - Energy Information Administration, *Residential Energy Consumption Survey: Household Energy Consumption and Expenditures 1997,*1999. <http://www.eia.doe.gov/emeu/recs/recs97/publicusefiles.html>

2. U.S. Department of Energy - Energy Information Administration, *Residential Energy Consumption Survey: Household Energy Consumption and Expenditures 1993,* October*,* 1995. Washington, DC. Report No. DOE/EIA-0321(93).

3. Whirlpool Corporation, *Comments to the Department of Energy, p. 1 and 2, Attachment #1, December 12, 1990, Docket No. CE-RM-90-201,* 1990.

4. The Life Expectancy/Replacement Picture*. Appliance Magazine*, 2000. 57(9): p. 87

5. National Oceanic and Atmospheric Administration, 1998. (Last accessed July 17, 1998). <http://www.ncdc.noaa.gov/ol/climate/online/ccd/meantemp.html>

6. U.S. Department of Energy-Office of Codes and Standards, *LCC Spreadsheets: Electric, Gas, Oil,*2000. If you have any questions or are unable to access the web site, please contact Ms. Brenda Edwards-Jones at (202) 586-2945 or by fax at (202) 586-4617, <http://www.eren.doe.gov/buildings/codes_standards/applbrf/waterheater.htm>

7. U.S. Department of Energy - Energy Information Administration, *Annual Energy Outlook 2000: With Projections Through 2020,* December*,* 1999. Washington, DC. Report No. DOE/EIA-0383(2000). <http://www.eia.doe.gov/oiaf/aeo/>

8. Lutz, J. D., X. Liu, J. E. McMahon, C. Dunham-Whitehead, L. J. Shown, and Q. T. McGrue, *Modeling Patterns of Hot Water Use in Households,* 1996, Lawrence Berkeley National Laboratory. Berkeley, CA. Report No. LBNL-37805.

9. Ladd, G. O. and J. L. Harrison, *Electric Water Heating for Single-Family Residences: Group Load Research and Analysis,* 1985, Gilbert Associates, Inc. Palo Alto, CA. Prepared for Electric Power Research Institute*.* Report No. EPRI EA-4006.

10. Lutz, J., C. D. Whitehead, A. Lekov, D. Winiarski, and G. Rosenquist, WHAM: A Simplified Energy Consumption Equation for Water Heaters. In *1998 ACEEE Summer Study on Energy Efficiency in Buildings*. 1998. Asilomar, CA, August 23-28, 1998: American Council for an Energy-Efficient Economy. 1: p. 1.171-1.183.

11. Lutz, J., C. D. Whitehead, A. Lekov, D. Winiarski, and G. Rosenquist, WHAM: Simplified Tool for Calculating Water Heater Energy Use*. ASHRAE Transactions*, 1999. 105(Pt 1)

12. *Title 10, Code of Federal Regulations, Part 430- Energy Conservation Program for Consumer Products, Appendix E to Subpart B- Uniform Test Procedure for Measuring the Energy Consumption of Water Heaters,* January 1, 1998.

13. Hiller, C. C., A. I. Lowenstein, and R. L. Merriam, *WATSIM User's Manual, Version 1.0: EPRI Detailed Water Heating Simulation Model User's Manual,* October, 1992, Electric Power Research Institute. Palo Alto, CA. Report No. TR-101702.

14. Paul, D. D., G. R. Whitacre, J. J. Crisafulli, R. D. Fischer, A. L. Rutz, J. G. Murray, and S. G. Holderbaum, *TANK Computer Program User's Manual with Diskettes: An Interactive Personal Computer Program to Aid in the Design and Analysis of Storage-Type Water Heaters,* July, 1993, Battelle Memorial Institute. Prepared for the Gas Research Institute. Report No. GRI-93/0186.

15. Minniear, M., *Residential Water Heaters: Initial Estimates of Manufacturing Costs and Energy Consumption,* November 12, 1997, Minniear Corporation. Panama City, FL. Report No. Task 1 of LBNL Subcontract No. 6466797.

16. Gas Appliance Manufacturers Association, *Consumers' Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment,* October, 1999. Cortland, NY. Prepared by Intertek Testing Services.

17. Labs, K., Underground Building Climate. *Solar Age*, 1979. 4(10): p. 44-50

18. Abrams, D. W. and A. C. Shedd, *Commercial Water Heating Applications Handbook,* 1992. Palo Alto, CA. Prepared for Electric Power Research Institute, Final Report, Research Project 3169-01. Report No. EPRI TR-100212.

19. California Energy Commission, *Occupancy Patterns & Energy Consumption in New California Houses (1984-1988),* 1990. Sacramento, CA. Report No. P400-90-009.

20. U.S. Department of Commerce-Bureau of Economic Analysis, *Survey of Current Business, National Data,*1999. <http://www.bea.doc.gov/bea/ARTICLES/NATIONAL/NIPA/1999/0899dpga.pdf>

21. Gas Research Institute, *1998 Edition of the GRI Baseline Projection,* 1998. Arlington, VA.

22. Pacific Northwest National Laboratory, *Telephone calls to residential oil-fired equipment dealers,* April, 1998. Richland, WA.

23. McMahon, J., *Quantities and Current Assumptions for Calculating Life Cycle Costs of Clothes Washers,* March 11, 1998. Research Memo to U.S. DOE, LBNL, Berkeley. CA.

24. Gas Research Institute, *2000 Edition of the GRI Baseline Projection of U.S. Energy Supply*

and Demand to 2015, 2000. Arlington, VA. Report No. GRI-00/0002.1.

25. U.S. Department of Energy-Office of Codes and Standards, *Marginal Energy Prices Report,* 1999. <http://www.eren.doe.gov/buildings/codes_standards/applbrf/pdfs/marginal_energy_price.pdf>

26. Applied Energy Group Inc, *Massachusetts Joint Utility End Use Monitoring Project: Final Report,* February 15, 1989. Woodbury, NY.

27. Consumers Power-Market Research & Pricing Department, *Residential Appliance Submetering Studies 1977-1984,* 1984. Jackson, MI. Report No. 84-273.

28. Eto, J. H. and M. M. Moezzi, *Analysis of PG&E's Residential End-Use Metered Data to Improve Electricity Demand Forecasts,* June, 1992, Lawrence Berkeley Laboratory. Berkeley, CA. Report No. LBL-32118.

29. Merrigan, T., C. D. Beach, O. Hancock, T. Tiedeman, R. McCluney, C. Cromer, D. W. Patzsch, T. J. Stryker, J. Burkett, R. Ramakrishnan, P. Ramakrishnan, and C. Svec, *Residential Conservation Demonstration: Domestic Hot Water,* September, 1983, Florida Solar Energy Center. Cape Canaveral, FL. Report No. FSEC-CR-90-83.

30. Parker, D. S., M. D. Mazzara, and J. R. Sherwin, *Monitored Energy Use Patterns in Low-income Housing,* 1996. Florida Solar Energy Center, <http://www.fsec.ucf.edu/~bdac/pubs/PF300/HHPPR.htm>

31. Pratt, R. G., C. C. Conner, E. E. Richman, K. G. Ritland, W. F. Sandusky, and M. E. Taylor, *Description of Electric Energy Use in Single-Family Residences in the Pacific Northwest: End-Use Load and Consumer Assessment Program (ELCAP),* July, 1989, Pacific Northwest Laboratory. Report No. DOE/BP-13795-21.

32. U.S. Department of Energy-Energy Information Administration, *Annual Energy Review Interactive Data Query System,* 1998. (Last accessed October 10, 1999). <http://tonto.eia.doe.gov/aer>

33. Gas Appliance Manufacturers Association, *GAMA Cost Data,* 1998. Received by LBNL on October 20, 1998.

34. Gas Appliance Manufacturers Association, *Statistical Release,* various years. Arlington, VA.

35. West, E., *Oil-Fired Water Heaters, Improvement to the Energy Use Attribute,* 1998. PNNL Subcontract No. 323519. Received by PNNL on August 14, 1998.